1971-12

GPGL: a model interactive, general purpose graphic language.

Beans, James Dale.

Monterey, California. Naval Postgraduate School

GPGL: A MODEL INTERACTIVE, GENERAL PURPOSE GRAPHIC LANGUAGE

James Dale Beans

NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

GPGL: A MODEL INTERACTIVE, GENERAL PURPOSE GRAPHIC LANGUAGE

by

James Dale Beans

Thesis Advisor: R.D. DeLaura

December 1971

GPGL: A Model Interactive, General Purpose Graphic Language

by

James Dale Beans
Major, United States Marine Corps
B.S., United States Naval Academy, 1957

Submitted in partial fulfullment of the requirements for the degree of

MASTER OF SCIENCE IN COMPUTER SCIENCE

from the

NAVAL POSTGRADUATE SCHOOL
December 1971

ABSTRACT

General Purpose Graphic Language (GPGL) is an interactive language which is intended for both two-dimensional and three-dimensional displays. The thesis contains a survey of the attributes and capabilities of an interactive general purpose graphic language. The more popular general purpose graphic languages are compared and the results included. The system and user-defined functions (including the construction of user-defined functions) of GPGL are explained. The implementation of a subset of GPGL at the Naval Postgraduate School on an Adage AGT-10 graphics terminal is described. The main purpose of implementing a selected subset of functions from GPGL is to examine the tri-level hierarchy established within the components of the graphical display; the manner in which this hierarchy is implemented is addressed in the thesis.

TABLE OF CONTENTS

ACKNOWLEDGMENT

The author wishes to express his appreciation to William Thomas of the Electrical Engineering Computer Laboratory, Naval Postgraduate School for his time and patience in assisting in the utilization of the Adage Graphics Terminal.

I. INTRODUCTION

With the advent of the digital computer and the expansion of the multitude of applications for the computer, the field of "Computer Graphics" has become of prime importance. Computer graphics refers to the use of a display device (usually a cathode ray tube) with auxiliary devices connected on-line to a computer. The cathode ray tube or other display device is used for graphic communications with the computer [1]. Computer graphics really came of age in 1963 when Sutherland used his Sketchpad graphic system to demonstrate the designing of various linkages and the analysis of the structural stress in a bridge.

As the years have passed and the uses for computer graphics have increased at almost an exponential rate, the need for a graphic language or languages has increased proportionally, therefore, the number of graphic languages since Sutherland's demonstration of the feasibility of computer graphics has greatly increased in the last eight years. These graphic languages range from extensions of common high-level programming languages (e.g., FORTRAN, ALGOL, etc.) to many highly specialized graphic languages which are designed to be used in only one area of application. Naturally, interest has been generated in general purpose graphic languages which could be used to assist in the many applications which require or use computer graphics.

The purpose of this thesis is threefold:

(1) To discuss certain considerations taken into account in selecting and designing the model language;

(2) To present General Purpose Graphic Language (GPGL);

(3) To discuss the implementation of General Purpose Graphic System (GPGSY), a basic subset of GPGL.

It was determined that GPGL would be, as much as possible, hardware independent. The only real hardware requirements in addition to a digital computer is that the hardware included a display device (general requirement for computer graphics), which is normally a cathode ray tube, some type of input/output attention device, (e.g., a light pen, mouse, joy stick etc.,)and a teletypewriter. Some type of input/output attention device and teletypewriter are normal components of a computer graphics system. It is intended that the GPGL be able to be implemented in its entirety (which will not be feasible in many cases because of the anticipated large core memory and/or auxiliary memory requirements) or partially implemented by selecting a desired subset as was accomplished at the Naval Postgraduate School. GPGL was designed to be extendable, meaning the user can develop more complex functions if he desires in accordance with his own programming skills. Lastly, GPGL is designed so that it can be utilized by students who have little or no programming experience or knowledge.

The thesis is devided into three parts. First, this thesis deals with the considerations taken into account in

determining GPGL. This includes a brief look at the development of graphic languages, what a graphic language is, and the more important attributes required of a general purpose graphic language. The latter includes a selection of the graphic capabilities which are required in a graphic language. The second part covers the functions of GPGL with the necessary description of what the specific functions accomplish, the inputs required for the function, and examples demonstrating how the language could be used. The last section deals with the implementation of GPGSY, an actual subset selected from GPGL, the directions for the use of the GPGSY, some examples of its use, and some of the more important matters considered in the implementation phase. The Computer Program used to accomplish the implementation is appended for further reference.

II. CONSIDERATIONS IN DESIGNING THE LANGUAGE

A. THE DEVELOPMENT OF GRAPHIC LANGUAGES

Graphic languages have not developed as rapidly as the more familiar programming languages. Probably the first uses of graphics were made in the early 1950's with the Whirlwind computer. In 1955, the APT (Automatically Programmed Tools) language was demonstrated on the Whirlwind. Even though APT is a specialized programming language, it does have the ability to be used in conjunction with computer graphics [2]. After 1957 when FORTRAN became popular as a normal programming language, and as computer graphics grew, it was natural for FORTRAN to be extended for computer graphics. This was done through the language GRAF [3]. As ALGOL became popular it was also extended for computer graphics under the name AED (ALGOL Extended For Design) [4]. Still in the development states at The Rand Corporation is an extension to a conversational subset of PL/I which could be used for computer graphics. The latter would give the user the ability to program in a conversational mode in the more powerful PL/I language [5].

An even more popular approach was the development of system graphic subroutines. At first these were designed to be used exclusively with FORTRAN. Examples of these are GSP [6] and DISPLAYTRAN [7]. IGS (Integrated Graphics System) was developed by The Rand Corporation and is a

subroutine package which the user can use with FORTRAN, PL/I or any of the other languages which have standard IBM Operating System/360 linkages [8].

Many other graphic languages were developed independently from the normal high-level programming languages. The early computer graphics system took the direct approach to "syntactic" representation, that is the display itself constituted sufficient representation [9]. As such, the dynamic graphical languages of SKETCHPAD [10] and CADET (Computer Aided Design Experimental Translator) [11] had a syntax of FUNCTION, BUTTON1, FUNCTION, BUTTON2 where FUNCTION was the selection of a function and BUTTON was the designation of the parameters of the function. This type of description was hard to explain and understand and is obviously very hardware-oriented. CADET is of interest because it demonstrated for the first time that a dynamic graphical language could be handled in the same manner as a verbal programming language. By developing a data structure of the binary tree type and by using a precedence table with many precedence pointers, the originators of CADET illustrated they could display a picture from data structure information. They showed that the process of constructing a display list to generate a display on a CRT from a data structure is analogous to the generation by a compiler of specific machine code instructions from source code statements [11]. More recently, graphic languages have also used metacompilers, compilers, interpreters, and

subroutine calls. The question of which to use will be examined in more detail later.

Many specialized graphic languages have been developed to handle specific application areas. CAFE is a language which was specifically designed to be used in the making of motion pictures and uses SNOBOL to handle the conversational mode between the user and the computer and to construct the data structure. FORTRAN is used to process the final data structure and perform the perspective transformations [12]. BUGSYS [13] and PDL [14] are languages or systems specifically designed to analyze and process pictures. These are just two of many specialized languages.

Only a few general purpose languages have been developed independently from the high-level programming languages. One of these languages was developed by Kulsrud [15]. Kulsrud's language is not only designed to construct displays, but is specifically designed to handle both topological and pictorial analysis. Kulsrud's general purpose language with its metacompiler is a good representative language of the present state of the art.

B. DEFINITION OF A GRAPHIC LANGUAGE

In the preceding paragraphs numerous references have been made to graphic languages which actually refer to graphic systems in toto (e.g., Sketchpad, IGS). In another case a translator, CADET, was referred to as a language. This ambigious definition of a graphic language is common

[illegible]

throughout the field of computer graphics. Morrison states:

> "The term "graphic language" has been used ambiguously, in the literature, to describe at least three different types of language used in graphic processing.
>
> 1. The input stream is in the form of actions taken by a console operator.
>   a. draw with light pen
>   b. type names and numbers
>   c. push buttons
>   d. light pen references of objects on the screen
>
> A language translator translates these actions into invocations of appropriate procedures. These procedures perform requested actions and provide displayed feed back to the user.
>
> 2. Input is in the form of pictures existing on film or other media. In this case, the language translator is a pattern recognizer which recognizes and extracts meaning from these pictures.
> 3. A set of programming tools (functions and subroutines) are embedded in a "host" language (e.g. FORTRAN). Using these tools lightens the load of the graphic system." [16]

When complete graphic systems are referred to, more than just the graphic language is included. Sketchpad, which is a program written for the TX-2 computer, is a complete system, not just a graphic language. It includes a complicated, ring-type data structure. The many different types and forms of data structures which can be used in implementing a graphic language comprise a separate subject, which is of sufficient importance and complexity to have warranted many studies in itself. But as Kulsrud stated, "Although the problem of data structure is a central one for graphics, it should not affect the graphic language design directly." Data structures are not a part of the graphic

language itself, but rather a component of a graphic system which is needed to implement the graphic language. Kulsrud further asserted that a complete graphic system would probably contain two or more different data structure types [15]. The Sketchpad system also makes use of the many buttons, knobs and toggle switches on the TX-2 computer. Although the order required in the selection of these hardware input devices determines the syntax of the dynamic graphic language used, the hardware and its input devices are not part of the actual language. Thus, when a graphic system is referred to, it implicitly determines a graphic language, but also includes additional components used to implement the language. Because of this, graphic systems are commonly referred to as graphic languages, and different graphic systems and graphic languages are often compared.

In order to clarify the situation, the author has supplemented a dictionary definition of language to define a graphic language for computers. The definition is the following: "a set or system of symbols or operations which can be used in a more or less uniform fashion to describe, generate and manipulate graphic displays on an input/output device which utilizes a digital computer to accomplish the necessary processing." This definition is felt to be adequate, but it is recognized that many other suitable definitions could be written.

C. A GENERAL PURPOSE VERSUS SPECIAL PURPOSE GRAPHIC LANGUAGE

There is some controversy whether one general purpose graphic language or many special purpose graphic languages are needed to accomplish the many and varied applications for computer graphics. Some leading scholars in the field believe that a specialized language is required for each application area if the graphic language is required for more than just drawing pictures [17]; [16]. Others feel that a language of utmost generality should be developed that permits its own modification [18]. There is, however, general agreement that a general purpose graphic language should have the capability of accomplishing more than just drawing a picture.

Since the uses for computer graphics are only limited by the imagination of man, any general purpose language, which was expected to be all-inclusive, would have to be used in the areas of computer-aided design, in drafting, in the design and analysis of electronic circuits, in the analysis of structural engineering, in numerical control in manufacturing, in the field of simulation, in the interpretation of pictures and the list would continue to grow on and on.

Notely stated that any display can be drawn theoretically by just three basic drawing commands (draw, rotate and move), but quickly adds that for most applications this method may be too cumbersome [19]. So, much more than just drawing

pictures is required and the applications are so varied that any one language that attempted to handle all applications would have to be either as basic as machine language, which is too cumbersome to use, or contain so many commands or procedures that it would take an extremely large storage capacity to implement. For example, Streit's VIP system which was designed only to draw displays took over 27,000 60-bit words to implement.

In the present state of the art, any so called high-level programming language, which is considered to be general purpose because it was designed to handle so many different areas of applications, such as PL/I, can not be efficiently or easily used for list processing, simulation and other specialized applications. Specialized languages have been developed to handle these more specialized applications. When a program is processed that utilizes only a small subset of the PL/I compiler, the efficiency, in regards to both time and storage of the utilization of the computer, is low. This is due to the fact that the PL/I compiler requires a larger amount of storage and takes longer to compile than many less complex compilers. All of the so-called general purpose, high-level programming languages, do have a common basic subset of capabilities which include data description and data transformation. In a similar manner, no one graphic language can be sufficiently general purpose to handle all applications. However, any general purpose graphic language (general purpose in the sense that the language can be used

with many varied applications) must have a basic set of required capabilities. To this subset of required capabilities, additional sets of supplementary capabilities are added, depending upon what specialized applications the language must handle. The required subset and these supplementary subsets then make up the graphic language. (See FIGURE 1.)

D. THE ATTRIBUTES AND CAPABILITIES OF A GENERAL PURPOSE GRAPHIC LANGUAGE

There are many different attributes and capabilities of a general purpose graphic language. The required subset of capabilities comprise those that are required while the supplementary subsets comprise those that are optional. The use or uses for which the language is designed is what determines what capabilities are included as optional.

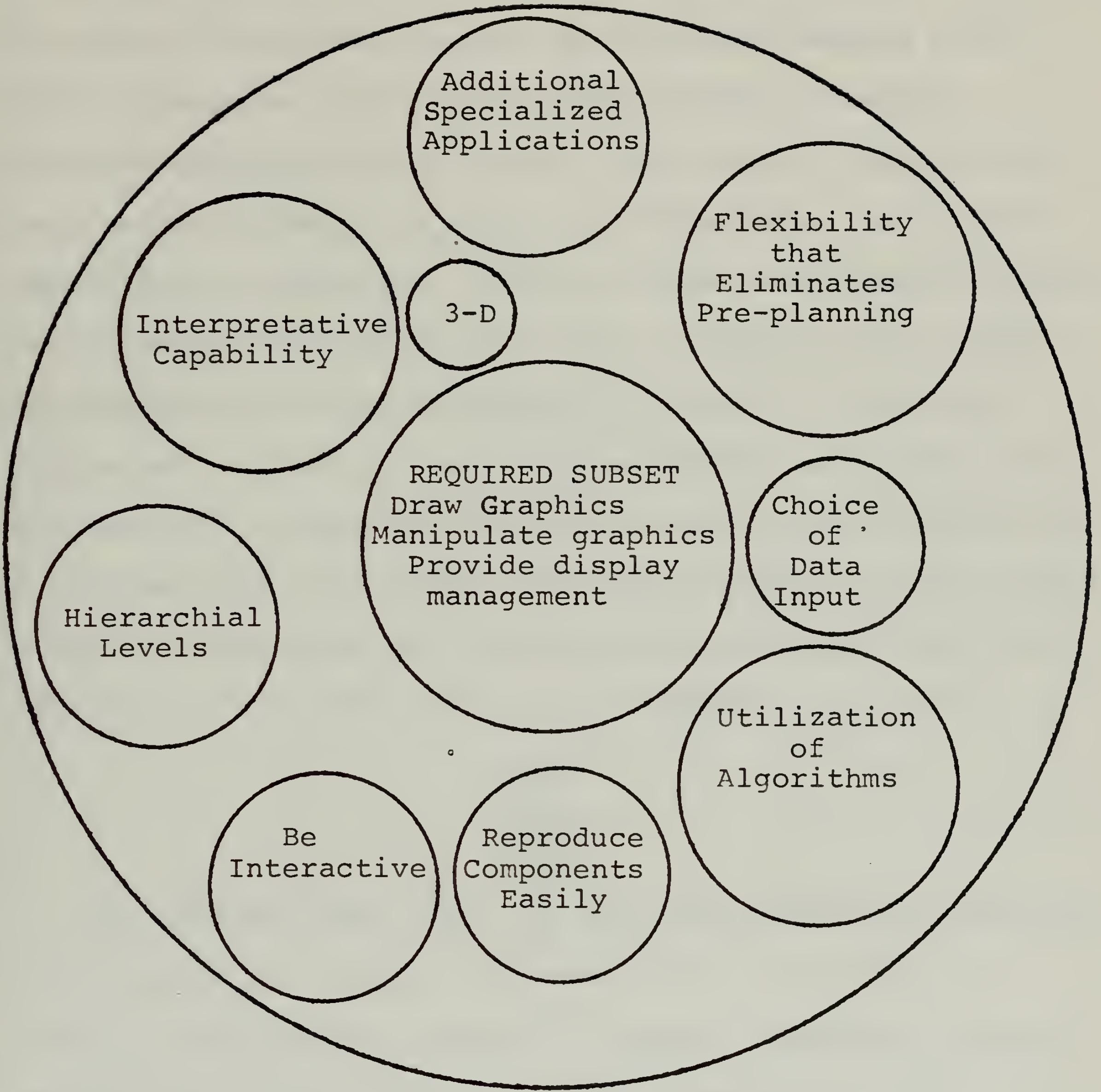
The basic requirements of a general purpose graphic language are:

(1) Draw graphics

(2) Manipulate graphics

(3) Provide display management

The most elementary requirement of a general purpose graphic language is that the language must describe and generate displays. In order to do this, the language must provide a capability of controlling the placement and intensity of points, line segments and possibly arc segments. In generating displays there are several different primitives which have to be considered. The basic building block


Additional Specialized Applications
Flexibility that Eliminates Pre-planning
Interpretative Capability
3-D
REQUIRED SUBSET Draw Graphics Manipulate graphics Provide display management
Choice of Data Input
Hierarchial Levels
Utilization of Algorithms
Be Interactive
Reproduce Components Easily

GRAPHIC LANGUAGE

FIGURE 1

is the line segment which is referred to as a line. Since the user of computer graphics is not beyond making a mistake, some means of correcting the mistake is needed. A complete blanking of the display with a start from scratch requirement is much too harsh and unforgiving, so an erase capability is mandatory. Titles, labels and numerical values are often used to amplify and explain displays so a means of entering text into a display is required. Since arcs, curves and circles are used frequently and generating them becomes such a tedious programming task, an arc function is a courtesy that the author feels every graphic system should provide. Therefore, the needed primitives which should be included in the subset of required capabilities are:

- LINE
- ARC
- ERASE
- TEXT

The language must give the user the ability to manipulate the displays by rotation and translation. In order to rotate a display efficiently, a rotation capability should be provided by the language. It is possible for the programmer to construct a program that accomplishes the rotation by drawing the component of the display in its new rotated position or, in the case of dynamic rotation, in incremental positions until the final position is reached. However, this defeats the purpose of a high-level programming language, which is to assist the user by easing the programming burden. A translation capability should also be provided

for the same reason. Both translation and rotation require some axis or point from which the objects can move or rotate. Some type of anchor point or reference point must be established, either by default or by selecting some specific point. Therefore, the graphic language should have the capability of selecting and changing this reference point. The required manipulators are:

ROTATE
TRANSLATE
REFERENCE POINT

In order to properly and efficiently handle displays and their components, the language must provide for the rearrangement, merging, searching and sorting of the components of a display. A means of retaining and recalling more than one display is required for convenience and completeness. In order to provide a minimum capability in display management the following processes or functions are required:

STORE
FETCH
NAME

These capabilities are the functions that form the required subset of any general purpose graphic language and as such are just the basic necessities of the language.

The main optional attributes and capabilities of a general purpose graphic language are:

(1) Be interactive

(2) Provide hierarchial levels within the display

(3) Provide an easy method of reproducing components within a display

(4) Provide a flexibility that eliminates extensive preplanning

(5) Provide an interpretative capability

(6) Provide for the utilization of algorithms

(7) Provide a choice of data input

(8) Provide a three-dimensional capability

For most applications, one of the most desired attributes of a general purpose graphic language is that it be interactive. For example, computer-aided design, which can include all types of creative design, is one of the most popular uses for computer graphics. In order to efficiently utilize computer graphics in this manner, it is necessary for the graphic language to be interactive. If the language is not interactive, the creativity of the human is greatly limited. The required time lapse between input, result and input will cause the user to lose his concentration on the subject. In many cases the user might be required to work on a different problem or application between inputs in order to efficiently utilize his time. To be truely interactive, the language must not only have a rapid response, but must also be forgiving if the user commits an error. If the remedial action required is too complex or time consuming, the interaction between the user and the system will be lost. The language can not be too complex or hard to learn for the same reason. The language should be open-ended (its capabilities easily extended). If the user arrives at a situation which he can not handle explicitly

within the capabilities of the language, there should be a means to extend the language through some programmable feature which should allow the user to maintain continuous thought while he implements the necessary extension.

The language should establish hierarchial levels among the various component parts of the display. This permits the user to allow the various levels to have specific characteristics (e.g., dynamic rotation of all components at one level or a specific intensity setting for all components below a component at a higher level). This capability would permit a display to depict a vehicle, which has wheels of two different sizes, in motion. The different sized wheels would be rotating at different speeds while the vehicle moved across the display. The number of levels that should be permitted is a moot point, but most scholars are in agreement that the language should be multi-level [9;15].

It is necessary for the general purpose graphic language to have an efficient method of reproducing components of a display since many displays contain elements which are similar except in size and/or location. When dealing with hardware which is limited to straight line segments, it is often necessary to approximate a circle with hundreds of small line segments. For the user to do this each and every time a circle is required, is a very inefficient method. The most efficient way of reproducing components is normally

through subroutines or procedures; therefore, it is necessary that a general purpose graphic language have this capability.

An important capability to a graphic language is that of providing enough flexibility within the language to eliminate any extensive prior planning. The present batch-type operating system in normal computer processing requires complete prior planning. This is not desirable and can not be accomplished in many computer graphics applications. As Chen and Dougherty state, "In interactive problem solving, unanticipated situations frequently arise that make complete preplanning difficult or impossible." [20] Gaglians and his co-authors assert:

> "Thus, effective use of graphics devices for interactive problem solving requires some means for requesting that a data processing system perform functions not anticipated at the beginning of the problem solving process." [7]

The flexibility is needed because in most cases the user will create or design some new display. In many cases the user will have very few preconceived ideas and will tax the imagination in creating a display. The freedom from pre-planning every construction is critical in interactive computer graphics. The user often does not know exactly what steps to take while creating a display so the user can not always create a normal type program prior to the execution phase. One way of providing this flexibility is to permit the user to return to a common point in the processing

which allows the branching to many, if not all, the functtions or processes provided by the language.

Some graphic languages restrict the user to only constructing displays, (e.g., DRAWL [21] and VIP [9]). This restriction severely limits the use of these languages. As Roberts stated,

> "However, the ability to make pictures is not sufficient in itself; the pictures must be representative of data which needs computation such that the graphics system is used as an input/output tool, not merely as a display."[17]

By having the capability to interpret displays, the computer can be utilized more effectively. There are several different ways a display can be interpreted. The most obvious is by topological analysis (i.e., analyzing the relation of one subelement of a display with respect to another). Another type of analysis is that which examines and locates special features in pictures (which the present state of the art normally handles through a digital photograph scanner [15]. It is desirable that a general purpose graphic language have the capability to handle elementary topological analysis from which more sophisticated analysis can be programmed.

Most users desire the capability of specifying algorithms in order to provide a more dynamic flexibility in the operation of the display console. By having this capability the user can use conditional statements, do-loop sequences and arithmetic statements. The capability is also important when the user is programming the display device primarily as an output device.

Some languages require certain data inputs only through a light pen or other attention devices, while others require the same data input solely through a keyboard device. Often the type of input device or devices are limited by the funds available to the computer installation for purchasing hardware. In other cases data may be more easily entered by one means than another. Therefore, it is desirable that the language permit the user the option of choosing the desired method of input.

Numerous uses of computer graphics are more suited to three-dimensional viewing than two-dimensional viewing. The work of Johnson, as demonstrated by Sketchpad III [22], and Roberts [23] have shown that it is possible to effectively use computer graphics in a three-dimensional representation. Rotation, magnifications, translation and perspective transformations can be accomplished by a single 4 X 4 matrix developed by Roberts [23]. The implementation of the three-dimensional aspects of a graphic language is a subject worthy of a complete study in itself. For extremely complex displays, such problems as determining hidden lines are too costly in computer time and storage to make three-dimensional displays practical. These problems can be circumvented by using wire frame displays or making some other compromise. If a three-dimensional capability is needed additional capabilities should be provided. Hidden or invisible lines should be available to the user to fully develop a display. This capability provides the user with the ability to have

[illegible]

objects appear as they do in real life (with their hidden lines), yet any analytic routines can operate on the complete object. A dash-line function often assists the viewers of a three-dimensional display to get a proper perspective because the user can dash the hidden lines. Three-dimensional representation has proven not only to be very effective, but also to increase greatly the creativity of the user.

These optional capabilities form supplementary subsets which can be added to the subset of required capabilities as needed. Other specialized capabilities can also be added for more specialized applications. (See FIGURE 1.)

E. A COMPARISON OF VARIOUS GENERAL PURPOSE GRAPHIC LANGUAGES

A comparison of some of the more interesting general purpose graphic languages is shown in Table 1 and is amplified in the following paragraphs.

1. Sketchpad

Although Sketchpad was created in 1963 it has many features that few, if any language, explicitly provides. At the touch of a button, lines can be made perpendicular, parallel, or be manipulated to meet other constraints. A "lock on" feature is provided that permits the user to terminate a line segment exactly upon intersecting another component. Pictures and subpictures provide hierarchial levels for the system. Points can be designated as attachment points on subpicture components; moreover, the

	ARC or CIRCLE	ROTATE	COPY	HIDDEN LINES	HIERARCHY	TOPOLOGICAL ANALYSIS	PICTURE ANALYSIS	CONSTRAINTS	HARD COPY	EXTENDABLE	COMPLEMENTARY LANGUAGE
SKETCHPAD	E	E	E	NO	2	M	NO	E	E	NO	NONE
GSP	P(L)	P(L)	P(L)	P(L)	P(L)	M	NO	P(L)	P(L)	M	FORTRAN
GRAF	P(L)	P	P(L)	E	P(L)	M	NO	P(L)	P(L)	NO	FORTRAN
GRAPHSYS	E	E	E	E	10	M	NO	P(L)	E	NO	AED MAD
IGS	E	P(L)	P(L)	P(L)	P(L)	M	NO	P(L)	E	NO	FORTRAN PL/I
VIP	E	E	E	NO	3	NO	NO	P	E	E	NONE
KULSRUD	E	E	E	NO	2	E	E	P	E	E(L)	FORTRAN MAD

SYMBOL LEGEND

E- Explicitly provided by the language	(L)- Provided by or in conjunction with a complementary language
P- Capable of being programmed	2, 3, or 10- Number of hierarchial levels established
M- Capability provided to a minimal degree	NO- Language does not have the capability

TABLE 1.

components can be joined at these selected positions. A component can be copied at the touch of a button. These are just a few of the many sophisticated features provided by Sketchpad. Sketchpad is a complete graphic system. It was specifically designed for the TX-2 computer. The input statements are completely hardware dependent and the language established by these statements can not be extended without a major change to the system. Sketchpad provides a graphic system with many unique features to the user. But even more important is the fact that it established the feasibility of computer graphics to the world [10].

2. Graphics Subroutine Package (GSP)

GSP consists of some basic subroutines which give the user a very elementary graphics capability. A simple program which does nothing but construct an arc becomes a relatively complicated task in GSP. Since GSP is designed to be used with FORTRAN, most graphic functions are obtainable by brute force programming. More recent developments permit GSP to be used in conjunction with COBOL or PL/I. The general form is CALL NAME (PARAMETER1, PARAMETER2, etc.) which is quite unwieldly when many parameters are required. GSP with the usual version of FORTRAN is more effective as a language that uses the display screen as an output device since all input device signals must be anticipated when the FORTRAN program is written. As previously discussed, many applications of computer graphics can not be pre-planned, so in many cases the input device signals can not be

anticipated. This drawback to GSP can be over come with the use of an incremental compiler or interpreter as was done with DISPLAYTRAN [7]. With interpretive FORTRAN execution, the attention device signals can be anticipated as the need for their use occurrs and no extensive pre-planning is required [24].

3. GRAF

GRAF provides basically the same capabilities provided by GSP with the exception that GRAF is an extension of FORTRAN, thus used exclusively with FORTRAN. One advantage of GRAF is that subroutine calls with their many parameters are avoided. As the authors of GRAF state, "Further, we feel that coding, debugging and simply understanding the logic of a program from its listing are all made much easier by avoiding CALL statements with long argument lists for frequently needed graphic routine." [3] Both GRAF and GSP were an attempt to ease the burden of programming on the graphics user. Since FORTRAN was probably the most commonly used programming language at the time, it was felt that by allowing the user to program in FORTRAN it would be easier for him than requiring him to learn a completely new language for graphics. An incremental compiler or interpreter should be used with GRAF because the same problem arises handling attention signals in GRAF as was described for GSP (i.e., the attention signals must be anticipated) [3].

[illegible]

4. <u>GRAPHSYS</u>

GRAPHSYS is a set of procedures or subroutines which is written in AED. Although GRAPHSYS was specifically designed for use at the Electronic Systems Laboratory, MIT, it is not as hardware dependent as Sketchpad since AED is a machine-independent language. GRAPHSYS could be implemented without many major modifications at other installations with adequate computer hardware. GRAPHSYS is part of a larger time-sharing system which is the mode that many graphics systems will use in the future. GRAPHSYS has many interesting features which are intended to ease the programming burden on the user. These include specific functions to accomplish such things as drawing a circle, making a copy and constructing hidden lines. A hierarchial level is provided among the components of a display. The language permits a depth of ten levels referred to as subpictures. These give the user a great deal of flexibility in constructing his display. GRAPHSYS was specifically designed to handle three-dimensional graphics so hidden lines and other functions needed with a three-dimensional display are available [4].

5. <u>Integrated Graphics System (IGS)</u>

IGS is a graphic system which is hardware independent, although implemented on the IBM 2250 graphic display console. It can be used with any language which has OS/360 linkages (e.g., FORTRAN, PL/I, Simscript 1.5 and OS/360 assembly languages). IGS is composed of many procedures or subroutines designed to handle the graphic functions necessary in

creating and manipulating the graphic displays. Calls to IGS routines are made from within the user's program. Parameters are handled either by the normal passing with the call or by using a special parameter array (200 locations). This array contains what could be considered the default values of the parameters in question. Since IGS provides only the elementary graphic functions, a user is required to write a rather complex program to construct even simple displays. For example constructing a simple circle would be a tedious task. An incremental compiler or interpreter should be used because attention device signals have to be anticipated or they will be ignored as was the case with GSP and GRAF [8].

6. Visual Interpretive Processing (VIP)

VIP is also a complete graphics system which was designed solely to draw displays; therefore, it does not qualify as a true general purpose graphic language. It is an interesting graphic system because it allows almost complete flexibility to the user. Little or no programming experience is required to use the system; yet more sophisticated programs can be constructed through "programmed functions" which are developed by the user at the display console. The complexity and sophistication of these programmed functions depends on the programming expertise of the user. A function interpreter carries out the execution of both the programmed and system functions. The interpreter fetches the code of the programmed functions into core,

permits nested functions by utilizing a stack, and handles various error conditions (i.e., infinite looping and illegal addressing). Attention device signals can be handled as they occur, which eleiminates the requirement to pre-plan the signals. This technique gives the user great flexibility in designing a display. The system is relatively hardware independent and provides two hierarchial levels. An algorithmic program can be developed through the programmed function capability [9].

7. Kulsrud's Model Language

Kulsrud's model graphic language is felt to be a true, general purpose language, designed to describe, generate, manipulate and analyze displays. In Kulsrud's article, he discussed only a typewritten version of his language, but he explained that this is done for convenience and to facilitate understanding. He states that this version could be translated to suit the graphic equipment available using light pen and control button sequences. Kulsrud included the basic statements necessary to conduct both topological and other forms of picture analysis. He did not design his language to be used with three-dimensional displays which is a limitation. Kulsrud used a metacompiler, which used incremental compilation, to produce interactive graphic programs. This permits immediate testing of language syntax on a line by line basis and the immediate detection of most typographical errors. Kulsrud's language has three

hierarchial levels and was designed to be used in conjunction with the normal high-level programming languages, FORTRAN and MAD [15].

F. DISCUSSION OF SYNTAX VERSUS SUBROUTINE APPROACH TO GRAPHICS

In the previous discussion of graphic languages and their implementation, there were basically two approaches used to implement the languages. Either a series of subroutine calls with their required parameters are made to graphic procedures stored in a library, or a syntax for the graphic language is specified and then the language is complied or interpreted by standard techniques. In the latter case some programs are compiled as an entire program while others are compiled line at a time by an incremental compiler. Since an interactive mode is desired, compilation should be on a line at a time basis. This was the method used in Kulsrud's graphic system [15]. When using subroutines to accomplish the graphic functions, some systems compile the subroutines prior to storing them so they are available in machine code for execution as the user desires. Other systems store the subroutines in their high-level language and then compile the routines with the entire program as they are called. The more desirable method is to compile the subroutines prior to storing them in order to decrease the time required to execute the procedure. This capability may involve dynamic loading with its overhead.

When considering the user inputting statements and/or data via the display console, either method has the capability to utilize attention devices (e.g., light pen, Rand tablet, mouse, etc.) to a maximum, keeping typewritten inputs to a minimum. It is usually more natural and quicker to point a device at a location on the display to determine the position of a point, rather than calculating the desired coordinates and then typing the coordinates into a typewriter. If the attention devices are used to the maximum, it is irrelevant to the user, inputting the information via the display console, whether the subroutine or syntax approach is being used.

If, on the other hand, the user is inputting statements and/or data via some non-graphical input device, which method used does become of interest. As previously mentioned, using subroutine calls with the many required parameters is quite unwieldly at times. However, the subroutine approach is usually more easily extended than the syntax method. Normally a subroutine can be programmed and placed in the system library more easily than the incremental compiler can be changed in the syntax method. This drawback to the syntax approach has been largely overcome by the metacompiler which makes the necessary changes to the graphic compiler as implemented by Kulsrud [15].

The subroutine approach is often more flexible because the subroutines may be used with many different languages. In considering the more recent syntax type graphic languages,

some of them have been designed to be implemented in conjuction with several high-level programming languages.

Graphic languages, in general, can be specified by their syntax as demonstrated by Morrison [16] and others. The syntax approach normally has a smoother program flow than that of the subroutine method. Both approaches have advantages and disadvantages; thus, the determination as to which method should be used should be decided on an individual basis for each computer installation. At an installation where the core memory is limited to such a degree that only a very carefully selected subset of a general purpose language can be implemented, the subroutine approach has a decided advantage. The selected subroutines can be implemented in a very basic language (i.e., assembly language or machine language); therefore, no large amount of storage is required for an incremental metacompiler, incremental compiler or interpreter as is the case of the syntax approach. Even if the sophisticated compiler is to be paged in and out of core memory, the increased complexity of the resident monitor will increase the storage required by the monitor which reduces the core memory available for the user. In the case of a large computer graphic installation (at least large in storage capacity), a syntax approach with its algorithmic-programming capability has an advantage because of the smoothness and flexibility that this method provides.

In comparing the installation where each approach could be implemented, the syntax method is the more difficult. Normally a system using the syntax method will require the services of a system programmer in order to program and maintain the required software. The subroutine approach can usually be programmed and maintained by the user so there is no necessity to hire a system programmer. The speed of execution is normally greater in the subroutine approach since the subroutines can be compiled into machine code and stored prior to execution.

III. GPGL, A MODEL INTERACTIVE, GENERAL PURPOSE GRAPHIC LANGUAGE

GPGL contains both the attributes which are required of a general purpose language and many of those that are optional. It includes the option of selecting two-dimensional or three-dimensional displays, the option of attention device inputs or keyboard device inputs, and the capability of constructing algorithmic programs. In addition, the language is intended to be conversational (i.e., every users action is met with some action or response from the computer). As previously mentioned the model could be implemented in its entirety or in a selected subset. Since the language is designed to handle most applications, it would require a great deal of memory storage if fully implemented; therefore, it is envisioned that implementing a selected subset would be more practical for most computer facilities.

A. AN OVERVIEW OF GPGL

GPGL is designed to provide the user with two different types of functions with which the user can accomplish the desired tasks. These functions are called system functions and user-defined functions. The system functions are provided explicitly within the language (e.g., rotation, translation, etc.), while the user-defined functions are designed by the user to accomplish the specific process or processes desired. The user-defined functions are normally

programmed by the user through teletype-system and teletype-editor commands. The functions are built by using the many available system functions as the basic elements from which a program is constructed for each user-defined function. The program is compiled and the user-defined functions stored under a unique name awaiting call.

The user accomplishes the desired tasks by first selecting whether a two-dimensional or three-dimensional display (no mixed mode is permitted) is desired. Then the user selects a series of system and/or user-defined functions from a "menu" (a list of optional choices) shown on the display console. The choice of how many and what functions are selected is basically determined by the user (some ordering is required by the language in respect to the input mode - attention device or teletype) which gives the user the necessary flexibility usually required in computer graphics as previously discussed.

The language provides a tri-level hierarchial structure. The basic or lowest level is an image, which is a component of a subpicture. Subpictures in turn compose or form a picture. Theoretically, there is an unlimited number of images in a subpicture and an unlimited number of subpictures in a picture. In actuality the number of either is limited by the storage capacity of the hardware available and the actual restrictions created by the implementation of the language. These images, subpictures and pictures can be uniquely named, and then stored and retrieved

through their name. Although it is envisioned that three hierarchial levels should be sufficient for most applications, the language could be extended in hierarchial depth without too much difficulty. GPGL could be extended in a similar manner to that used in GRAPHSYS [4]. This extension, however, would decrease the available user's storage capacity because of the need to store the necessary pointers and directories required to extend the hierarchial capability.

To assist in the visualization of the hierarchial levels included in the display and to permit the user to protect portions of the display that have been completed, a foreground and a background is established within the display. The foreground consists of the images which have not yet been stored in a subpicture (foreground makes up the current subpicture) while the background is composed of the subpictures which at the time make up the current picture. The primitives can effect only the foreground which provides a degree of protection to the subpictures and picture composing the background. It is intended that when GPGL is implemented the background portion of the display appear with a lower intensity than the foreground to assist the user in visualizing the hierarchial levels.

GPGL was specifically designed for some type of system which uses the subroutine approach to computer graphics in the implementation of the language. Specific teletype system commands were included that would permit programs written in other languages to be entered if the compiler in

[illegible]

the system could compile the other language or languages involved and store them as subroutines. GPGL could be used with a system which uses the syntax approach to computer graphics with some appropriate changes. These matters depend on the actual installation and the specific system used to implement the language. See the discussion of the syntax versus subroutine approach to computer graphs (paragraph II. F.).

When the user selects the three-dimensional mode, changes in the method of entering certain types of data are required. Since all locations in the viewer's space (three-dimensional space which the viewer would see if real objects were observed) have three dimensions it is necessary to enter three coordinates instead of the normal two. Different viewing conventions are required than those used in normal two-dimensional displays because the display screen is two-dimensional while the objects in the display are visualized in three dimensions. A convention implemented by Johnson with Sketchpad III is used [22], which includes three orthogonal and one three-dimensional perspective view. (See FIGURE 2.) It is envisioned that the system implemented would allow the user to increase the size of any of the four quadrants to fill the entire screen when selected. The four quadrants are not four independent displays, but are all interrelated so that an arc being drawn in one view is displayed in the other three. GPGL was designed to be implemented by using the three-dimensional, homogeneous

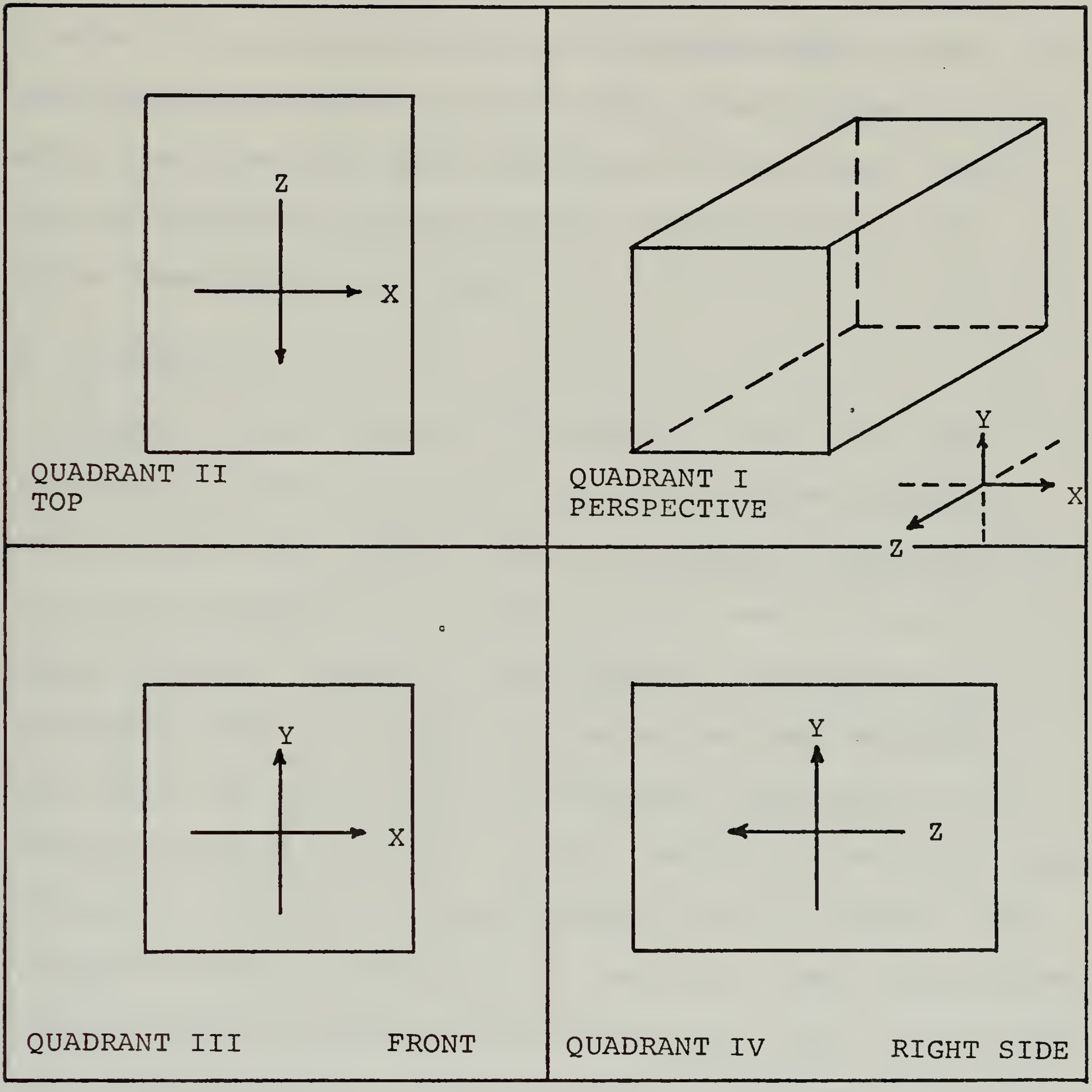

Z
X
QUADRANT II
TOP
QUADRANT I
PERSPECTIVE
Y
X
Z
Y
X
QUADRANT III
FRONT
Y
Z
QUADRANT IV
RIGHT SIDE

FIGURE 2

coordinate system developed by Roberts [23]. When entered in a typewritten-type mode, each point designated would be a series of four numbers. Two designations are required if a point is to be selected by an attention device input. A designation is made on the two appropriate orthogonal views which specifies the three dimensions of the point. This type of system was implemented by Johnson with his Pen Space Location Program [22].

B. FUNCTIONS

There are two levels of functions. The lower level functions or basic processes are called system functions and give the user control over each specific operation that is to be performed (e.g., draw a line, erase a line, etc.). These functions require no development or programming on the users part; the functions desired are just selected. This gives the user with no programming experience or expertise the ability to sit at the console and construct simple displays. The user-defined functions are the higher level functions and are programmed by the user. They are programmed through the user-defined instruction set. This set includes the system functions (whose arguments now become operands), the teletype system commands and the text-editor commands. The user-defined functions permit the use of an algorithmic approach in order to develop relatively complicated programs. User-defined functions can have either externally or internally specified operands which give the user a great deal of flexibility.

1. System Functions

System functions consist of primitives, manipulators, storage and retrieval functions, teletype function, and dimension selection functions. Functions which have a "-TT" suffix require teletype input or some other type of keyboard device input and the suffix is intended to act as a reminder to the user.

Most of the functions have parameters that can vary from points, to images, and in some cases to subpictures. A point can be located by several different methods. These methods are:

(1) selecting the point with an attention device input (two selections are required in the three-dimensional mode);

(2) by entering the X-coordinate, Y-coordinate (the Z-coordinate and the scale factor in the three-dimensional mode) through a keyboard device;

(3) by entering a unique name which has been previously assigned to the point.

In order to avoid ambiguity, subpictures and pictures are selected by name while images can be selected by selecting a point in the image or by name. The noun "component" can refer to any of the three hierarchial levels. In describing each system function, the function name will be followed by a verbal description of the parameters to be entered with the function. The necessary remarks explaining the function are included under the function.

[illegible]

a. Primitives

The primitive functions are the most basic of any of the functions and as such are used to construct and form the displays. The primitive functions can only be utilized in the foreground (at the image level) of the display. The primitives are as follows:

(1) Point Function

POINT (coordinates)

Remarks: POINT establishes a point with its coordinates as assigned in the inputs. The user has the option to continue to define additional points without having to re-select POINT.

(2) Line Function

LINE (end point coordinates)

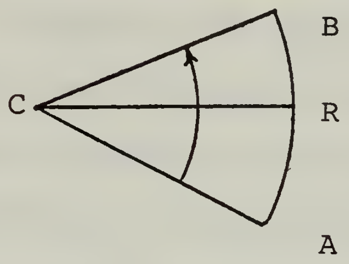
Remarks: Constructs a straight line segment joining the given end points. The coordinates of the end points are the parameters of the function. The user has the option to continue to draw lines by defining additional points without having to reselect LINE. Each additional point is the end point of a line segment from the previous point designated to the additional point last entered.

(3) Arc Functions

ARC (center (C), radius (R), delimiting point coordinates (A) and delimiting point coordinates (B))

Remarks: Constructs a circle segment (or circle) with the center at C and with line segment CR as the radius. The

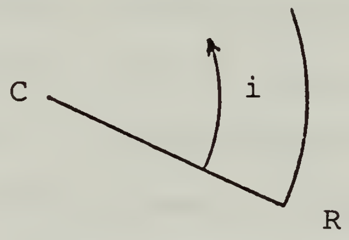
arc is determined by the angle subtended by the two line segments AC and BC as shown below:



If the two delimiting points, which are the third and fourth points entered, are omitted, a circle is drawn.

ARC-TT (center (C) and radius (R) point coordinates and the number of degrees (_i_))

Remarks: Constructs a circle segment (or circle) with the center at C and with line segment CR as the radius. The arc originates at R and extends through the number of degrees (_i_) entered in a counter clockwise direction as shown below:



(4) <u>Text Input Function</u>

TEXT-TT (coordinates of a point where the text is to be located, the size of the text desired and the string of text)

Remarks: Accepts the text message from the teletype and places it at the coordinates of the point entered. The system querys the user as to size of text and then requests the actual text message to be entered.

[illegible]

[illegible]

[illegible]

(5) Erase Function

ERASE (coordinates of a point in the selected image or the name of the image)

Remarks: Removes the designated image from the foreground display (releases or frees the storage previously utilized by the selected image so that the memory cells are available for use).

b. Manipulators

The functions that are used to manipulate and alter the images, subpictures and pictures are classified as manipulators. Some manipulative functions act upon either the current image, which is the image that is presently open for additions to its display list, or the entire subpicture, which is the foreground of the display. If the current image is still open, the manipulative function will act upon the image, if closed, the function will act upon the current subpicture, which is the foreground. (The storage and retrieval function NAME closes an image and is discussed in the next section.) The manipulative functions give the user the option of manipulating the current image or the foreground. If the user desires to manipulate the foreground, the current image must be closed. The manipulators are as follows:

(1) Reference Point Function

REF (coordinates)

Remarks: Designates the reference or anchor point. This reference point is the point which the image or foreground

will be manipulated around. The default value is the center of the display or in the case of the three-dimensional quadrant view, the center of each quadrant.

(2) <u>Translation Function</u>

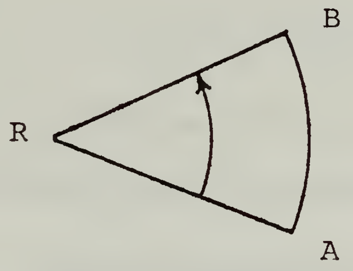
TRAN (coordinates)

Remarks: Translates the reference point from its previous position to the location entered. This causes the entire image or subpicture to translate the same distance and direction that the reference point moved.

(3) <u>Rotation Functions</u>

ROT (coordinates of two delimiting points (A and B))

Remarks: Rotates the image or subpicture about the reference point (R) in a counter clockwise direction through an angle subtended by the two line segments AR and BR as shown below:



(4) <u>Flip Function</u>

FLIP (factor)

Remarks: Reflects the foreground about a vertical axis through its reference point.

(5) <u>Zoom Function</u>

ZOOM-TT (factor)

Remarks: Magnifies the image of the subpicture by the

factor entered. If a negative number is inputed, the image or foreground is diminished (down to the limit of a point).

(6) Proportional Change In Size - X Axis

PROPX (coordinates of two delimiting points)

Remarks: Shrinks or expands the foreground symmetrically about a vertical axis through the reference point (RP) in the proportion:

$$(b_x-RP_x)/(a_x-RP_x)$$

where a_x is the X coordinate of the first point entered and b_x is the X coordinate of the second point entered.

(7) Proportional Change In Size - Y Axis

PROPY (coordinates of two delimiting points)

Remarks: Shrinks or expands the foreground symmetrically about a horizontal axis through the reference point (RP) in the proportion:

$$(b_y-RP_y)/(a_y-RP_y)$$

where a_y is the Y coordinate of the first point entered and b_y is the Y coordinate of the second point entered.

(8) Display Reference Point

DRP

Remarks: Displays the reference point of the image or subpicture as an asterisk.

(9) Dash Function

DASH

Remarks: Changes all the lines in the image or subpicture into a dashed representation.

(10) <u>Hidden Line Function</u>

HIDDEN

Remarks: Changes all the lines in the image or subpicture to an invisible mode. The lines are still present in the data structure even though the lines do not appear on the display console so interpretative functions can still be utilized with respect to the invisible component.

(11) <u>Intensity Function</u>

INTENSITY-TT (factor)

Remarks: Intensity of the image or subpicture is varied by the factor (within the limits prescribed by the hardware). If the factor is positive, the intensity is increased; and if it is negative, the intensity is decreased.

(12) <u>Graytone Function</u>

GRAYTONE

Remarks: Used to half-tone, that is, shade the image or subpicture. This capability has been successfully implemented as discussed by Sutherland [25].

(13) <u>Scale Function</u>

SCALE-TT (scale for X, Y, and Z)

Remarks: Defines the picture, with coordinate axes X, Y, Z, as being 2X units in width, 2Y units in height, and 2Z units in depth. The origin (0,0,0), resides at the center of the screen (center of each quadrant in the three-dimensional, quadrant view). The range is from -X to +X, -Y to +Y, -Z to +Z. This permits the user to use any scale desired whether it be miles, feet or whatever.

c. Storage and Retrieval Functions

In order to provide convenience and completeness to the user, various functions are needed to store and retrieve images into or from a subpicture, subpictures into or from a picture and pictures into or from a library. The storage and retrieval functions are as follows:

(1) <u>Frame Component Function</u>

FRAME

Remarks: Appends the current contents of the foreground display to that of the background display as in internal structure (subpicture). Automatically gives a unique subpicture number for retrieving the structure. (The user has the option of using the NAME function to give the structure a unique name). The intensity of the foreground is reduced in order to assist in the visualization of the hierarchial levels.

(2) <u>Store Picture Function</u>

STORE-TT (name)

Remarks: Stores the current contents of the background display in the storage area or library for pictures under the name entered.

(3) <u>Retreival Function</u>

FETCH-TT (name)

Remarks: Retreives the image, subpicture or picture, whose name is entered. If the component named is an image or subpicture it is displayed as part of the current foreground (the component must be a component of the current picture);

[illegible]

if the component name is a picture it replaces the present contents of the background display. Images and subpictures retreived are opened for the addition of vectors or other modifications.

(4) <u>Name Function</u>

NAME-TT (name)

Remarks: Assigns the name entered to the header (first location) of the designated image or subpicture (pictures are named by STORE-TT function). Each name must be unique to avoid ambiguity in retreiving the image or subpicture. In order to explicitly assign a name to a subpicture, NAME must be called immediately after FRAME. When NAME is used in regards to an image, it "closes out" the image. "Closes out" means that no additional vectors can be added to the display list of that image until the image is retrieved by the FETCH function.

(5) <u>Delete Function</u>

SCRUB-TT (name)

Remarks: Deletes the picture specified by the name from storage or the subpicture specified by the name from the background. Frees the storage previously utilized by the picture or subpicture which is scrubbed.

(6) <u>Clear Foreground Function</u>

CLRF

Remarks: Blanks the foreground display and frees the storage utilized by the images in the foreground display (in most cases the user will have stored the images desired for retention in a subpicture).

(7) <u>Clear Background Function</u>

CLRB

Remarks: Blanks the background display and frees the storage utilized by the subpictures in the background display (in most cases the user will have stored the picture desired in order to retain the subpictures and images).

(8) <u>Hard Copy Function</u>

PHOTO

Remarks: Generates a hard-copy of the entire console screen.

d. Keyboard Device Functions

When the user desires to input specific data which is normally entered by attention device through a keyboard device, the TTY function must be called.

TTY

Remarks: Alerts system that the normal input by attention device will be via a keyboard device. All inputs for the function must then be entered by a keyboard device. Functions which have the suffix "-TT" should not be followed by the TTY function unless the normal attention device inputs (if any) are to be entered via the keyboard device. For example, with ARC-TT if the first two delimiting points were to be entered by a keyboard device instead of an attention device the TTY function would be used.

e. Analysis Functions

Functions which interpret the topology and other pictorial features of a display are required in a general purpose graphic language. Certain basic analysis

functions are provided in GPGL which permit the user to develop more complex interpretative programs. Some functions return a value and print the value by teletype. If the function is used in a user-defined function, the teletype message is not printed.

(1) Within Function

WITHIN (coordinates of two points with each point designating an image, or two names designating images or subpictures)

Remarks: Checks whether the component entered first lies within the second component entered.

(2) Separate Function

SEPAR (coordinates of two points with each point designating an image, or two names designating images or subpictures)

Remarks: Checks whether the selected images or subpictures are separated. If there is no intersection of lines or points, and one component does not lie within the other, TRUE is returned and printed by the teletype, otherwise FALSE is returned and printed by the teletype.

(3) Simply-Connected Function

SIMPLY-TT (name of an image, subpicture or picture)

Remarks: Determines whether the designated component is a simply-connected region. (Simply-connected region is a region for which any closed curve lying in the region can be continuously shrunk to a point without leaving the region [26].)

(4) Region Assignment Function

REGSNAP-TT (property)

Remarks: Assigns each point in the display (picture) to a region, which has internally generated labels with the property selected by the parameter entered. This process is referred to as a region snap. Normally the property is color,(i.e., black, white and/or shades of gray [15]).

(5) Name Region Function

NAMEREG-TT (coordinates of a point, the property parameter and a name)

Remarks: Assigns the name entered as the name of the region, with respect to the property specified by the property parameter, which the selected point or component is in.

(6) Connection Functions

CONECT (coordinates of two points)

Remarks: Checks whether the two selected points are in the same region. If they are connected (in the same region), a TRUE is returned and printed by the teletype. If not, FALSE is returned and printed by the teletype.

CONECTBY-TT (coordinates of two points and a name of a component)

Remarks: Checks whether the two selected points are in the same region and whether the named component connecting the two points is in the region. TRUE or FALSE is returned and printed by the teletype.

(7) Adjacent Function

ADJAC (coordinates of two points or the names of two components)

Remarks: Determines the adjacency of the designated components. If the two components are in the same region a zero is returned and printed by the teletype. If the components are in adjoining regions, a one is returned and printed by the teletype. If otherwise, the number of regions plus one, intervening between the two regions containing the designated components is returned and printed.

(8) <u>Intersection Function</u>

INTERX (coordinates of two points or the names of two components)

Remarks: Determines whether the designated components intersect. If they intersect any where in the display, the intersection value for the property previously used in the region snap is returned and printed at the teletype, otherwise FALSE is returned and printed at the teletype.

f. Dimension Selection Functions

The user determines which display mode he is going to use, either a two-dimensional display or a three-dimensional display and then selects the appropriate functions. The dimension selection functions are as follows:

(1) <u>Two-Dimensional Function</u>

2-D

Remarks: User selects this function first if he is going to use the normal, two-dimensional display mode.

(2) <u>Three-Dimensional Function</u>

3-D

Remarks: User selects this function first if he is going to use the three-dimensional display mode.

(3) <u>Three-Dimensional View Functions</u>

QUADI

QUADII

QUADIII

QUADIV

Remarks: Enlarges the selected quadrant to full screen size on the display console. (Used in the three-dimensional mode only.)

(4) <u>Quadrant-View Function</u>

3-D VIEW

Remarks: Returns the display to a quadrant view. (Used in the three-dimensional mode only.)

g. Keyboard Mode Function

In order for the user to develop user-defined functions, it is necessary to enter a keyboard mode where teletype system and text-editor commands are inputed through the keyboard device.

TTYMODE

Remarks: Causes the keyboard mode to be entered.

GET (coordinates of up to four points)

Remarks: Used to enter attention device inputs during the execution of a user-defined function. Provides the capability of allowing external inputs, whose locations can not be determined by the user prior to the execution phase. (Used only with user-defined functions.) Permits the input of up to four points into pre-planned and allocated storage locations.

2. User-Defined Functions

The user-defined functions, which are constructed by the users, are subroutines written by the user, compiled and stored under a unique name and then executed when a user selects the function's name from the menu. Therefore, user-defined functions developed by one user can be used to advantage by any other user. This gives the system an excellent growth potential, limited only by the storage capacity of the function library. The user-defined functions can be stored in pages or other segments.

The functions are normally formed by using the user-defined instruction set, which contains the system functions, the teletype-system commands and the teletype-editor commands. The teletype-system and the teletype-editor commands are similar to the ones used by Streit [9]. The choice of using similar commands to those of Streit's was made after examining the languages and systems previously mentioned. Streit's teletype mode is more natural, easier to implement, and much simpler to use than those of the other graphic languages and systems. The capability of using external programs (written in a language acceptable to the systems' compiler) is an important addition to Streit's teletype system.

From the user's standpoint, the user-defined functions appear the same as system functions once written and compiled. All locations in a user-defined function are referred to a coordinate system local to the function.

This requires the user to use a scale instruction when the function locates primitives on the display screen. The local coordinate gives the system user great flexibility and freedom in applying user-defined functions (but requires that the implemented system map all data locations between the user-defined function and the system's display). The user-defined functions can have internally or externally specified operands which give the user the ability to define any needed locations or points at the time the function is formed or when the function is called. The format used to define the user-defined instruction set is as follows:

```
Label:     OPCODE     A;B;C;...
                         or
                      a;b;c;...
```

Remarks: A, B, C...are symbolic address labels which are local to the user-defined function and a, b, c... are numerical operands. The label portion of the instruction is formed by an identifier followed by a colon, while OPCODE is the operation code given in the user-defined instruction set. Parenthesis are used to show all the different variations of the basic instruction.

a. User-Defined Instruction Set

The user-defined instruction set contains instructions formed by using the system functions as the OPCODE with the functions inputs as OPERAND as shown below for the function LINE:

```
Label:     LINE     A;B
```

Remarks: Connects the points A and B to form a line segment, AB.

In addition to the system functions, the user-defined instruction set includes arithmetic, conditional and control instructions. These instructions give the user an algorithmic-type programming capability which allows more flexibility, especially in respect to using the interpretative functions.

The arithmetic instructions give the user the basic arithmetic operations required, which include assignment, addition and subtraction. These instructions can be used for all the coordinate values or for the individual coordinates. The individual coordinate values are shown in parenthesis. The arithmetic instructions are as follows:

```
(1)  Label:   SET    A;B
              (SETX
              SETY
              SETZ)
```

Remarks: Assigns B to A.

```
(2)  Label:   ADD    A;B
              (ADDX
              ADDY
              ADDZ)
```

Remarks: Adds the X, Y, Z components of points A and B and places the result in A.

```
(3)  Label:   SUB   A;B
              (SUBX
              SUBY
              SUBZ)
```

[illegible]

Remarks: Subtracts the X, Y, Z components of points B from A and places the result in A.

(4) Label: SWITXY A

(SWITYZ

SWITXZ)

Remarks: Assigns the X component of A the value of the Y component and the Y component the value of the X component. (Assigns the Y component of A the value of the Z component and the Z component the value of the Y component. Assigns the X component of A the value of the Z component and the Z component the value of the X component.)

The conditional instructions allow conditional branching which permits the user to transfer control if various conditions are met. The instructions are as follows:

(1) Label: NZX A;B

(NZY

NZZ)

Remarks: Tests the X component of point A, and if non-zero, transfer control to B, otherwise control is passed to the next instruction. The alternate instructions test the Y and Z component of point A respectively, if non-zero, they transfer control to B, otherwise control is passed to the next instruction.

(2) Label: ZRX A;B

(ZRY

ZRZ)

Remarks: Tests the X component of point A, and if zero, pass control to B, otherwise control is passed to the next instruction. The alternate instructions test the Y and Z component of point A respectively, if zero, they pass control to B, otherwise control is passed to the next instruction.

```
(3)  Label:    NGX    A;B
               (NGY
               NGZ)
```

Remarks: Tests the X component of point A, and if negative, transfer control to B, otherwise control is passed to the next instruction. The alternate instructions test the Y and Z component of point A respectively, if negative, they transfer control to B, otherwise control is passed to the next instruction.

```
(4)  Label:    PSX    A;B
               (PSY
               PSZ)
```

Remarks: Tests the X component of point A, and if positive, transfer control to B, otherwise control is passed to the next instruction. The alternate instructions test the Y and Z component of point A respectively, if positive, they pass control to B, otherwise control is passed to the next instruction.

The unconditional transfer instruction passes control to the designated symbolic address.

```
Label:   GOTO    A
```

Remarks: Transfers control to A.

b. Teletype-System Commands

The teletype system commands are used to create and manipulate the text and code of the user-defined functions. The format of the commands is:

COMD1 COMD2/FIELD.

The first two fields are the command portion, where COMD1 specifies whether the command pertains to a function, picture or an external program, which is entered as a user-defined function. COMD2 is the action that the command is to perform. The remaining portion, which is FIELD, is the argument for the command. The command and field portion are separated by a slash and the instruction is ended with a period. Some instructions have no COMD1 portion and/or argument so the command portion consists of only an action part and the FIELD portion may be blank. The slash and period are always required. The command portion may be abbreviated to the first letter of the two fields (the underlined character or characters in each instruction). Blanks are used as delimiters except between the command and its argument where the slash is the delimiter. The teletype-system commands are as follows:

(1) Definition Command

FUNCTION DEFINE/NAME.

Remarks: This command opens a user-defined function titled NAME by entering the text-editor mode. When the user has completed his function, the text and code are stored under the symbolic address, NAME in the function library.

(2) Modification Command

FUNCTION MODIFICATION/NAME.

Remarks: Fetches the text of the present user-defined function with the symbolic address NAME. Deletes the code and enters the test-editor mode.

(3) Purge Command

FUNCTION PURGE/NAME.

Remarks: Deletes the text, code, and entry points for the user-defined function NAME.

(4) Change Name Command

FUNCTION NAME/OLDNAME NEWNAME.

Remarks: Changes all the entry points associated with the user-defined function OLDNAME to NEWNAME.

(5) Fetch Command

FUNCTION FETCH/NAME.

Remarks: Fetches the text for the user-defined function NAME.

(6) Fetch Code Command

FUNCTION CODE/NAME.

Remarks: Fetches the code for the user-defined function NAME.

(7) List Functions Command

FUNCTION LIST/.

Remarks: Lists all the user-defined functions in the function library.

(8) List Picture Command

PICTURE LIST/.

Remarks: Lists all the pictures in the picture library.

(9) External Program Input Command

PROGRAM INPUT/NAME.

Remarks: Accepts programs as inputs through paper tape, punched cards or other input devices acceptable to the implemented system. These programs can be in machine code or any high-level programming language which the system's compilers can compile. These programs are compiled and stored as a user-defined function executable on call. (Modification and Fetch system commands can not be executed on the external programs, which are in some other programming language.)

(10) Exit Teletype Mode Command

RETURN/.

Remarks: Teletype mode is exited and the user is returned to the function menu selection mode.

c. Text-Editor Commands

The text-editor commands permit the user to construct or modify the user-defined functions. The text-editor mode is entered by executing either the definition or modification teletype commands. The command format for the text-editor commands is similar to that used for the teletype-system commands. The format consists of:

COMD1 COMD2 COMD3/TEXT.

where COMD1 is the action indicator and COMD2 and COMD3 are the arguments. TEXT is the text lines of the user-defined function and consist of a label portion (LABEL:), an OPCODE portion and an OPERAND portion, which contains the arguments

of the functions in the OPCODE. Since some commands have only one argument or no arguments, COMD2 and COMD3 may be blank. Some TEXT lines have no label, so the label portion may be blank. If, instead of entering a text line, an existing text line is manipulated, the TEXT portion is blank. Blanks are used as delimiters except between the command portion and TEXT where the slash is used. The slash and period are required for all instructions. The text-editor commands are as follows:

(1) Next Text Line Command

NEXT/TEXT.

Remarks: Enters TEXT as the next line of the text-editor display.

(2) Insert Text Line Command

INSERT a/TEXT.

Remarks: Enters TEXT as the line above line a and below line a-1.

(3) Purge Text Line Command

PURGE a/.

Remarks: Deletes line a, and moves all the lines a+1 and greater up one line.

(4) Move Text Line Command

MOVE a b/.

Remarks: Deletes text line a and moves all the lines up one line and then inserts same text line, which was removed, above line b.

(5) Replace Text Line Command

REPLACE a/TEXT.

Remarks: Replaces the line a with TEXT.

(6) Compile Command

COMPILE/.

Remarks: Compiles the text displayed and loads the text and code into the function library under the name associated by the definition or modification teletype system commands. The system returns from the text-editor mode into the normal execution mode.

d. Examples of a User-Defined Function

In order to demonstrate the procedures required in constructing a user-defined function, two examples are discussed. The first example describes those teletype-systems commands and text-editor commands, which would be utilized in constructing the function. The second example shows only the text lines which make up a user-defined function in order to demonstrate the finished product.

The commands and the sequence in creating a user-defined function named HORIZON, which takes a given line and creates a horizontal line with the same X coordinates for its end points, are shown below with amplifying comments. The system functions are designated as (SF); the teletype-system commands are designated (TS); and the text-editor commands are designated (TE). The abbreviated format for the teletype-system and the text-editor commands is not used for clarity. A carriage-return character, which

signifies the end of each instruction, is not shown. The lines three through fifteen are used to construct the text lines which will accomplish the actions discussed in the comment portion when the user-defined function is executed.

NUMBER	COMMANDS	TYPE	COMMENTS
1	TTYMODE	SF	User selects the teletype mode with an attention device input.
2	FUNCTION DEFINE/HORIZON.	TS	Enters the text-editor mode with the name HORIZON, which is associated with the function to be constructed.
3	NEXT/ 2-D.	TE	Selects 2-D representation.
4	NEXT/ SCALE 500;500.	TE	Determines the local scale of the function to be 500x500.
5	NEXT/ CLRF.	TE	Clears the foreground.
6	NEXT/ GET A;B.	TE	Accepts two attention device inputs upon execution and loads their coordinates into the OPERAND portion of locations A and B
7	NEXT/ REF A.	TE	Moves the reference point to point A.
8	NEXT/ LINE A;B .	TE	Draws a line segment from point A to point B.
9	NEXT/ SETX TEMP;B.	TE	Assigns the X component of B to the X component of point TEMP.
10	NEXT/ SETY B;TEMP.	TE	Assigns the Y component of point A to Y component of point TEMP.
11	NEXT/ ROT B;TEMP.	TE	Rotates the image (line AS about A through the angle B-A-TEMP.*
12	NEXT/ RETURN.	TE	Returns control from the subroutine HORIZON.
13	NEXT/A POINT.	TE	Creates the symbolic address A and designates it as a point.

14	NEXT/B POINT.	TE	Creates the symbolic address B and designates it as a point.
15	NEXT/TEMP POINT.	TE	Creates the symbolic address TEMP and designates it as a point.
16	COMPILE/.	TS	Compiles the function HORIZON and stores the text and code in the function library under HORIZON and returns control from the teletype mode. * The line segment AB is horizontal, but the length has been changed.

The text and amplifying comments for a user-defined function named PARALLEL, is shown below. The user-defined function HORIZON is used. A carriage-return character which signifies the end of each instruction is not shown.

NUMBER	FIELD1	FIELD2	FIELD3	COMMENTS
1		2-D		Selects 2-D representation.
2		SCALE	500;500	Determines the local scale to be 500,500.
3		CLRF		Clears the foreground.
4		GET	A;B;C;D	Accepts four attention device inputs and loads them in OPERANDS of lines 12, 13, 14, 15.
5		SET	TEMP1;B	Sets point TEMP1 equal to point B.
6		HORIZON	A;B	Calls the user-defined function HORIZON, which makes line segment AB horizontal.
7		HORIZON	C;D	Calls the user-defined function HORIZON, which makes line segment CD horizontal.
8		NAME	PARA	Names and closes image (PARA) so that next command will act on foreground.
9		REF	A	Moves the reference point to point A.

10		ROT	B;TEMP1	Rotates the foreground (lines AB and CD) about point A through the angle B-Z-TEMP1.
11		RETURN		Returns control from the subroutine parallel.
12	A	POINT		Creates the symbolic address A which is a point.
13	B	POINT		Creates the symbolic address B which is a point.
14	C	POINT		Creates the symbolic address C which is a point.
15	D	POINT		Creates the symbolic address D which is a point.
16	TEMP1	POINT		Creates the symbolic address TEMP1 which is a point.
17	TEMP2	POINT		Creates the symbolic address TEMP2 which is a point.

C. EXAMPLES OF THE USE OF GPGL

The use of GPGL (implemented in an imaginary graphics system) is demonstrated in the following examples. The procedures are described by listing in chronological sequence the functions and inputs which would be utilized by a user if he were actually at a console programming. The displays are kept relatively simple for clarity and ease of comprehension. The attention device inputs which are required to locate components of the display (i.e., points, lines, etc.) are considered to be light pen hits (abbreviated as LP) and numbered sequentially (e.g., LP1, LP2).

Teletype inputs are shown in capital letters and underlined. The selection of the actual functions used is represented by the name of the function with no attempt to show what method of selection would be used (i.e., light pen picks, depressed function switch, etc.).

A two-dimensional display is developed to draw a geometric pattern which is named EMBLEM and then manipulated.

ORDER	FUNCTION	ARGUMENTS	COMMENTS
1	2-D		User selects the two-dimensional mode.
2	CLRF		Clears foreground (not required if already clear).
3	CLRB		Clears background (not required if already clear).
4	LINE	LP1;LP2; LP3;LP4	Draws a triangle from LP1 to LP2 to LP3 to LP4 (LP4=LP1).
5	NAME-TT	A C/R	Names the triangel A.
6	LINE	LP5;LP6; LP7;LP8	Draws a triangle from LP5 to LP6 to LP7 to LP8 (LP8=LP5).
7	NAME-TT	B C/R	Names the triangle B.
8	FRAME		Frames trianges A and B into a subpicture.
9	NAME-TT	TRIANGLES C/R	Names the subpicture TRIANGLES.
10	CLRF		Clears the foreground.
11	ARC	LP9;LP10	Draws a circle with LP9 as center and the radius the line segment from LP9 to LP10.
12	FRAME		Frames the circle.
13	STORE-TT	EMBLEM C/R	Stores the picture named EMBLEM, which consists of two triangles and a circle.
14	CLRB		Clears the background.
15	CLRF		Clears the foreground.
16	FETCH-TT	EMBLEM C/R	Fetches EMBLEM from storage and displays it in the background.
17	FETCH-TT	TRIANGLES C/R	Fetches subpicture TRIANGLES and displays it in the foreground.
18	ROT-TT	90 C/R	Rotates the foreground (both triangles) 90 degrees CCW.
19	FETCH-TT	A C/R	Fetches image A (triangle A).
20	DASH		Dash function is called and triangle A is dashed.
21	CLRB		Clears the background.
22	FRAME		Frames the dashed line triangle A and triangle B into a subpicture.
23	STORE-TT	TRI C/R	Stores the picture named TRI which is composed of triangle A, which is a dashed triangle, and triangle B both rotated 90 from the original subpicture TRIANGLE.

A three-dimensional display composed of a rectangular solid is constructed. FIGURE 3 shows the solid and the alphabetic designation of its corners, which are enclosed in parenthesis in the example.

ORDER	FUNCTIONS	ARUMENTS	COMMENTS
1	3-D		Selects the three-dimensional representation.
2	SCALE	10;10;10 C/R	Sets the scale for each axis from -5 to +5. (ABCD)
3	LINE	LP1,LP2;(A) LP3,LP4;(B) LP5,LP6;(C) LP7,LP8;(D) LP9,LP10(A)	Constructs the front (ABCD) of the solid.
4	GRAYTONE		Shades the front (ABCD) a lighter gray.
5	NAME-TT	FRONT C/R	Names the square (ABCD) FRONT and closes the image.
6	LINE	LP11,LP12;(A) LP13,LP14;(D) LP15,LP16;(H) LP17,LP18;(E) LP19,LP20(A)	Constructs the right side solid (ADHE).
7	GRAYTONE		Shades the side (ADHE) to lighter gray.
8	NAME-TT	SIDE C/R	Names the right side (ADHE) SIDE and closes the image.
9	LINE	LP21,LP22;(D) LP23,LP24;(C) LP25,LP26;(G) LP27,LP28;(H) LP29,LP30(D)	Constructs the top of the solid (DCGH).
10	GRAYTONE		Shades the top a lighter gray.
11	NAME-TT	TOP C/R	Names the top (DCGH) TOP.
12	LINE	LP31,LP32;(B) LP33,LP34;(F) LP35,LP36(E)	Constructs the lines BF and FE.
13	HIDDEN		Lines (BEF) are changed to the invisible mode.
14	NAME-TT	EDGE C/R	Names lines (BFE) EDGE.
15	LINE	LP37,LP38;(F) LP39,LP40(G)	Line (FG) is drawn.
16	HIDDEN		Line (FG) is changed to the invisible mode.
17	NAME-TT	REAR C/R	Names line (FG) REAR.
18	FRAME		Entire solid with its hidden line becomes a subpicture.

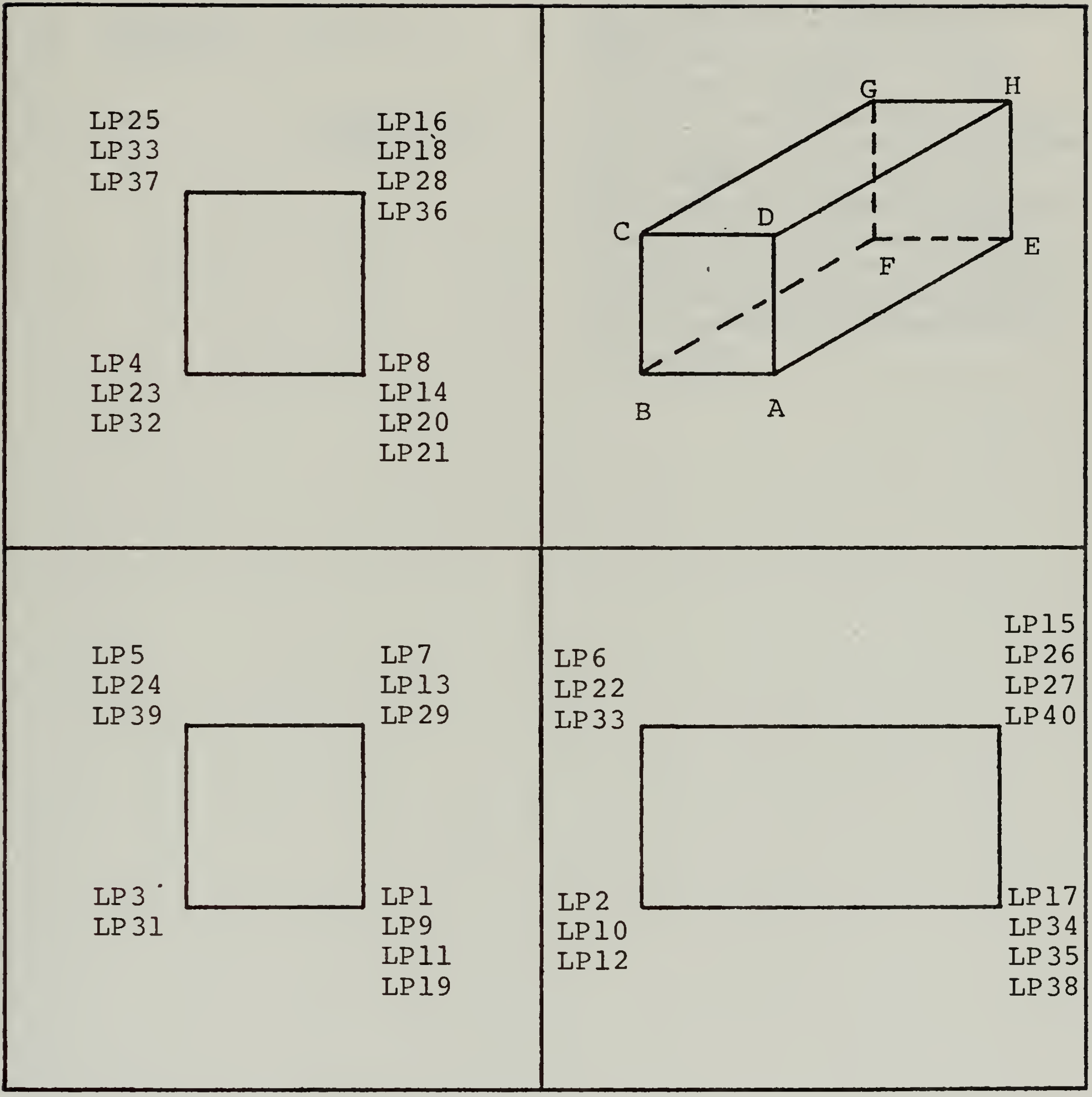

LP25
LP33
LP37
LP16
LP18
LP28
LP36
LP4
LP23
LP32
LP8
LP14
LP20
LP21
G
H
C
D
E
F
B
A
LP5
LP24
LP39
LP7
LP13
LP29
LP3
LP31
LP1
LP9
LP11
LP19
LP6
LP22
LP33
LP15
LP26
LP27
LP40
LP2
LP10
LP12
LP17
LP34
LP35
LP38

FIGURE 3

19	NAME-TT	BOX C/R	Subpicture is named BOX.
20	POINT		Point function is called.
21	TTY	2;2;-3;.75 C/R	Normal attention device input mode is changed to teletype mode and coordinates of X=2, Y=2, Z=-3 and scale of .75 are entered.
22	NAME-TT	Q C/R	Names point entered Q.
23	WITHIN		Calls the interpretative function WITHIN.
24	TTY	Q;BOX C/R	Usual attention device input mode is changed to teletype mode and Q and BOX are entered. Then the interpretative function WITHIN determines whether point Q is in BOX and prints either TRUE or FALSE through the teletype.

IV. IMPLEMENTATION OF GPGSY, A SUBSET OF GPGL, AT THE NPS

A. OBJECTIVES

GPGSY, a subset of GPGL, was implemented at the Electrical Engineering Computer Laboratory at the Naval Postgraduate School. The purpose was to illustrate some of the problems that are encountered in actually implementing GPGL into a graphic system. (The fact that a primitive graphics system, which is extremely easy to utilize and which will be easy to extend, is not available at the NPS is only a by-product.) The primary objective in selecting the subset to be implemented was to examine the problems encountered in having a tri-level hierarchial language. The necessary pointers and directories to implement the image, subpicture and picture concept were of specific interest.

There are many reasons why a subset was implemented in lieu of the full GPGL language. The overriding reason was the impossibility of fully implementing GPGL with the hardware available at the computer laboratory. The fact that only a subset can be implemented is expected to be the rule instead of the exception for most computer installations. GPGL was specifically designed so that personnel at a computer installation can select a desirable subset, which both meets the needs and the capabilities provided by the available hardware. The selection of the subset at NPS tested this hypothesis.

GPGL was designed to be hardware independent and this was important since the subset had to be implemented on the specific hardware available at the laboratory. A desired capability for a general purpose language is that it be interactive; GPGSY presented an opportunity to see if at least a portion of GPGL was truely interactive. It was also desired to examine the feasibility of giving the user the option of entering data either by attention device signals or teletypewriter as permitted in GPGL.

B. THE IMPLEMENTED SUBSET

GPGSY is an interactive, general purpose graphics system which permits the user to construct two-dimensional displays on a cathode ray tube (CRT). (The hardware utilized was not designed for three-dimensional representation.) GPGSY requires a storage capacity of 1,843 30-bit words and is written in ADEPT, an assembly language. The ADEPT program with explanatory comments is appended to the thesis.

The system was implemented on an Adage Graphics Terminal, Model 10. The nucleus of the system is the Digital Processor, DPR2, which is a general purpose digital computer with a two microsecond memory cycle time and one microsecond register to register transfers. The core memory size is 8K with a 30-bit word length. A two pack disk drive is available for auxiliary storage. The graphics terminal consists of a cathode ray tube (CRT), teletypewriter, a vector generator, a character generator, a light pen and sixteen function

switches. A resident monitor (AMRMX) is used to store and retrieve programs from the disk pack, to process programs, and to control various system components. Portions of the monitor are explicitly used in implementing GPGSY by calling on it to receive and print teletype messages.

With the primary objective of examining the hierarchial levels in mind the primitive functions of LINE, (drawing a line, which is the basic building component) and ERASE (the capability to erase an image) were selected. LINE was, of course, necessary in order to construct a display, and ERASE was of interest because of the problem of erasing the line or lines at the right hierarchial level.

The manipulative functions implemented were REF (designating the reference point for the images or subpicture), TRAN (translation of the images or subpicture), ZOOM-TT (enlarge or dimish the image or subpicture) and DASH (change all lines in the image or subpicture to the dash mode). The REF function was chosen because it was needed in order to have an anchor point or reference point to manipulate the images around. The translation function was chosen as the main manipulative capability because it could be more easily implemented. It provided the same problems in respect to the hierarchial levels as the other manipulative functions. A function to increase and decrease the size of the images was desired; therefore, ZOOM -TT was selected as the best function to provide this capability. The problem of which hierarchial level should be changed to the dashed representation

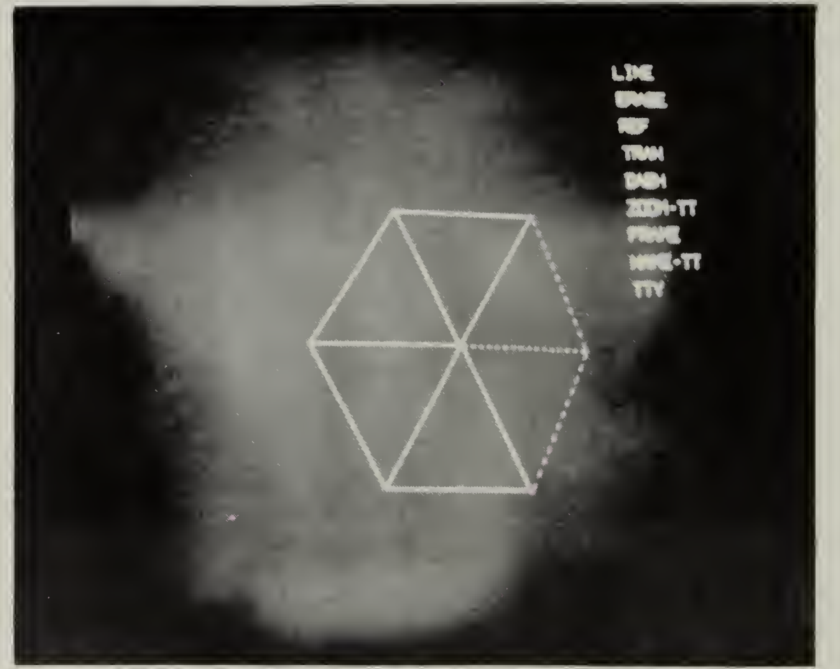
[illegible]

was of sufficient interest to warrant the inclusion of the DASH function to the subset.

The storage and retrieval functions included in the subset are FRAME (forms and sequentially numbers subpictures) and NAME (forms and names images, and names subpictures). The function NAME is used to close out an image - group all the components (i.e., lines arcs and points) drawn since the previous image was closed out into one image - by placing a unique name in its header cell. FRAME closes out one subpicture and opens the next in a similar manner to the closing of the images by NAME. FRAME also automatically numbers the subpictures for future reference.

The function TTY was implemented. This gives the user the capability of entering point locations for LINE, REF, and TRANS by teletype.

The operating procedures utilized by a user are discussed below, from the standpoint of the actions required by a user and the responses that the system makes. The user loads the program, GPGSY, and executes it with the normal monitor commands. The nine functions appear on the CRT listed as a menu in the right margin. (See FIGURE 4.) The user selects the function LINE with a light pen pick and a cursor appears at the center of the screen. The user using the light pen guides the cursor to the desired position. When the cursor is in position, the user depresses function switch 1 (FNSW1), which stores the location in the display list as a move (vector with the beam blanked). Then the user guides the



DISPLAY DRAWN WITH
GPGSY

MENU FOR SELECTION

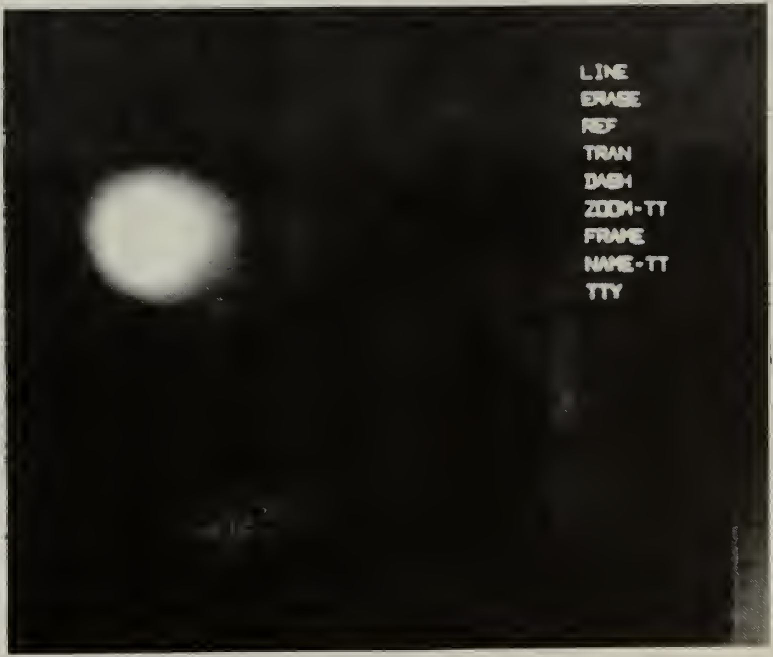


FIGURE 4

cursor to the next desired position and designates this point by again depressing FNSW1. This action places the selected location in the data list as a draw and a line segment appears with the two selected locations as the end points. The user continues drawing line segments as long as desired. The entering of line segments is only limited by the available core storage. When the user selects any of the other functions from the menu, the cursor disappears and some other interactive action takes place. Teletype messages giving the appropriate directions are used as responses so the user can utilize the system with hardly any prior instruction. After creating some object on the screen, the user can select any of the other eight functions.

The specific actions, which take place when a user selects a function by a light pen pick, are as follows:

(1.) <u>ERASE</u>

The teletype prints the following message, "SELECT IMAGE TO BE ERASED WITH LIGHT PEN." The user then takes a light pen pick on one of the lines to be erased and the entire image containing this line is erased from the screen.

(2.) <u>REF</u>

The cursor appears in the position of the present reference point. The user guides the cursor to the desired position and depresses FNSW1, which loads the new reference point into storage. All manipulative functions are now accomplished in respect to this new reference point.

(3.) <u>TRAN</u>

The cursor appears at the position of the present reference point. The user guides the cursor in the direction and the distance desired and then depresses FNSW1. The image or subpicture then translates in the direction and the distance that the cursor moved.

(4.) <u>DASH</u>

When the user selects this function, all the lines in the entire image or subpicture become dashed.

(5.) <u>ZOOM-TT</u>

The teletype prints the following message "INPUT UP TO 5 OCTAL DIGITS, NEGATIVE DIMINISHES." The user then inputs the incremental change in size that is desired. The function automatically limits the input from 0 (the image is shrunk to a point) to 37777 (the maximum size that the vector generator can scale a vector).

(6.) <u>FRAME</u>

The teletype prints the following message "SUBPIC_ CLOSED, SUBPIC_ OPENED" with the appropriate numbers in the blanks. No further action is required of the user.

(7.) <u>NAME-TT</u>

The teletype prints the following message "INPUT UP TO 5 CHARS." After the user enters the name of the image in five characters or less, the following message is printed by the teletype, "IMAGE CLOSED, NEW IMAGE OPENED."

(8.) <u>TTY</u>

The teletype prints the following message, "INPUT POINT (10 OCTAL DIGITS)." The user types in the coordinates of the point and in the cases of REF and TRAN no further action is required. With LINE, the teletype prints, "INPUT NEXT END POINT (10 OCTAL DIGITS) OR * TO END," and continues to accept points in this manner to draw a contiguous figure.

All the functions have appropriate messages which are typed by the teletype when the user commits an error, when all the images in a subpicture are used, or when all the subpictures are filled.

One of the original principles of the design of GPGL was to keep it as hardware independent as possible. GPGSY uses a CRT, teletypewriter, digital computer, light pen, one function switch, vector generator and character generator. Any computer graphics installation should have these devices (the character generator might be a software item), so the selected subset of GPGL can be considered relatively hardware independent. The hardware does certainly effect the implementation and in the case of GPGSY, the operating procedures. The vector generator develops new X and Y coordinates for the end points of the vectors which are to be drawn by the following formulas:

$$X'=DX+SC(X)$$

$$Y'=DY+SC(Y)$$

(X' is the new X coordinate, DX is a translation or offset increment, X is the old X coordinate and SC is the scale factor. Same for Y.)

The DPR2 has a hybrid array which automatically adds the DX and DY to every point in the display list. The register containing DX and DY is used in both TRAN and REF functions. The interesting point is that if an image is diminished by ZOOM-TT, the image is diminished, but the distance the image is from the reference point is also diminished because of the above formulas. If the user desires to diminish or magnify only the figure drawn, the user must move the reference point to the figure before using ZOOM-TT. Then ZOOM-TT is selected, the figure is diminished or magnified in position. This presents no serious problem to the user, but it does demonstrate the fact that the hardware (to be efficiently used) will dictate an order to execution for specific actions.

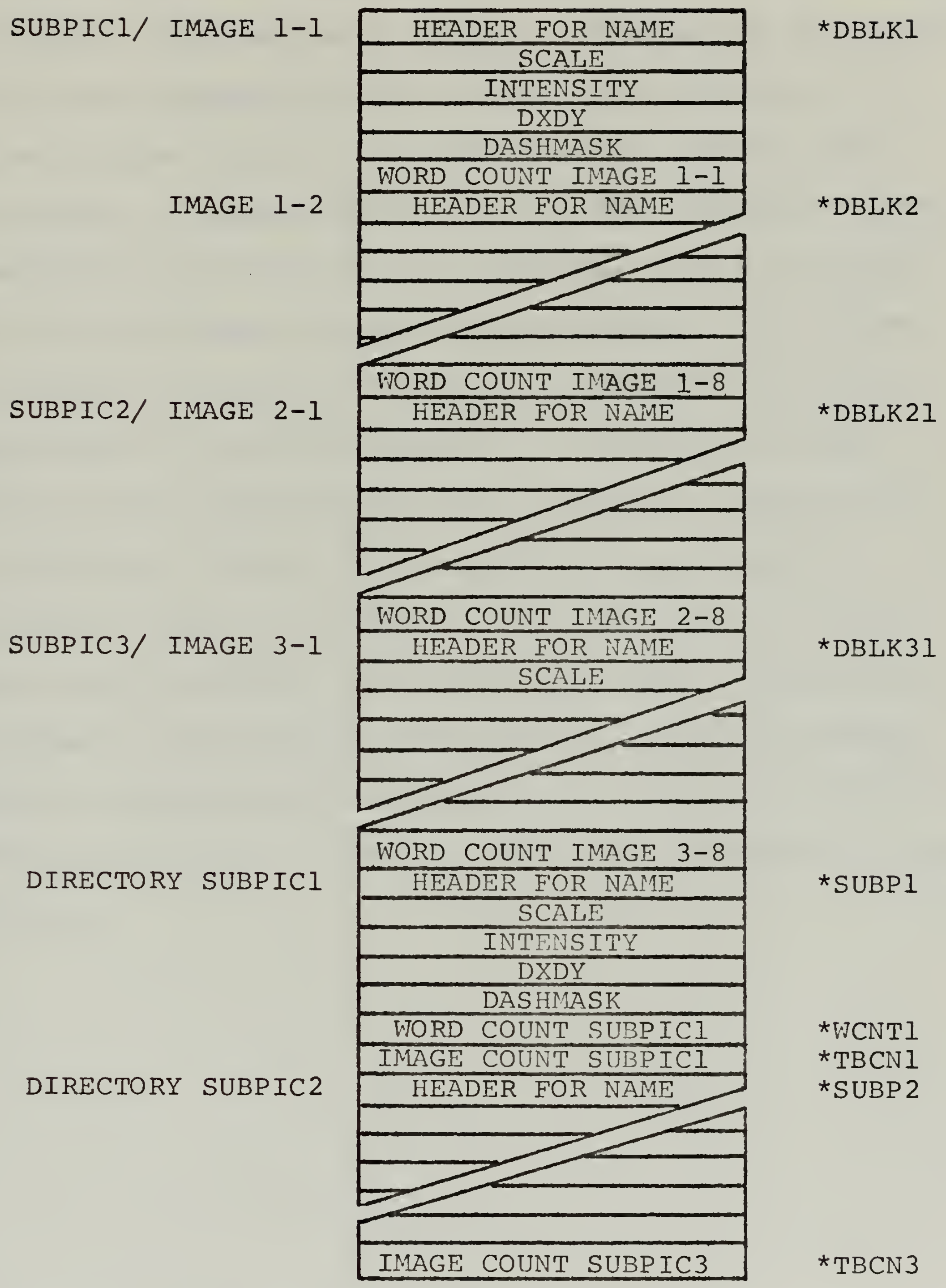
There was no problem implementing GPGSY in a conversational mode (a rapid computer response for each action of the user). Not all responses are graphical since many teletype messages are used as responses. This permits a user with little or no programming experience to use GPGSY, which is one of the design goals for GPGL.

The most interesting aspect in implementing GPGSY was the approach to a tri-level hierarchy within the components of the developed display. The lowest level, the image, is composed of any number of lines with the same scale, intensity and offset increments (DX and DY). Each image has a six cell directory which includes a header cell for the name, a cell for the scale, a cell for the intensity, a cell for DXDY, a cell for a dash mask (which is filled with an appropriate

mask when DASH is selected for the image) and a cell for the word count (the word count is the number of words in the display list and this number is loaded into the cell when the image is closed). Eight of these image directories make up a subpicture directory. The subpicture directory consists of seven cells which include the same six cells as the image directory plus a cell for the number of images filled in the frame (all eight images may not be used when the subpicture is closed). The system has three such directories; therefore, the picture can contain three subpictures. Thus, the directories form one large picture directory broken into three sequential subpicture directories; which in turn are broken into eight separate image directories. (See FIGURE 5.) The pointer for the directories is initiated pointing to the header of the first image in the first subpicture directory and is moved by computing an offset which is added to the pointer as the vector generator proceeds through the display list.

GPGSY provides up to 24 images contained in three subpictures, which make up one single picture. Any of the images can hold as many lines as the user desires up to the limit established by the available free core memory (4220 cells). This hierarchial level has cost the user using GPGSY a total of 165 memory cells. This storage loss could be reduced by about one third by loading scale, intensity, name and word count into half words and loading two words into one cell of the image directories. (Since

PICTURE DIRECTORY



*Variable names used in the computer program.

FIGURE 5

storage utilization was not a serious consideration and utilizing half words increases the complexity of the system this was not implemented in GPGSY.) Considering this savings, a tri-level hierarchy using the basic philosophy used in GPGL would cost the user approximately 110 memory cells per picture, or approximately 35 cells per subpicture added. If additional capabilities are required, such as rotation, this cost in storage would increase slightly. The three level hierarchy is quite adequate for demonstrating the capabilities of computer graphics to computer-oriented students and is adequate for most electrical engineering applications. Certain applications in the mechanical engineering field, especially those that pertain to gear trains and the movement of pistons and their related parts, may require more than the three levels provided by GPGSY. If these special applications are to be handled by GPGSY, the number of hierarchial levels of the system would have to be increased.

V. CONCLUSIONS

One of the considerations taken into account in selecting GPGL was the possibility of developing a single general purpose graphic language to handle all computer graphic applications. Although GPGL is a general purpose graphic language in that it can be used with many varied graphic applications, it is not suitable for all computer graphic applications. A mechanical engineering application, which would require more than three hierarchial levels, could not be effectively implemented with the present version of GPGL. Since many installations will use intelligent terminals with a small memory storage capacity, an all-inclusive general purpose language with its tremendous storage requirements could not be utilized by these installations. Most user's would use only some of the capabilities which would be provided by a single, all-inclusive general purpose language so that time and storage utilization would not be efficiently used. For maximum efficiency, a graphic language, which provided only the capabilities desired by the users, should be implemented. With the present state of the art, it is not feasible to design and create a single graphic language which can be used efficiently for all known applications of computer graphics.

In considering whether the subroutine or syntax approach should be used to implement a graphic language, it was previously mentioned that both approaches have advantages and

[illegible]

[illegible]

disadvantages. The decision as to which method should be used must be decided on an individual basis. Since the syntax method usually requires larger memory storage capacity and more programming expertise, it is felt that with the present state of the art, more installations will use the subroutine approach than the syntax approach.

The basic capabilities required of a general purpose graphic language can be provided with the following functions:

LINE
ARC
ERASE
TEXT
ROTATE
TRANSLATE
REFERENCE POINT
STORE
FETCH
NAME

GPGL provides all these functions plus many optional capabilities. The analysis capability and user-defined function capability are two of the more important options. The analysis capability is explicitly provided so that the user can do more than just draw pictures. The ability to program user-defined functions in GPGL gives the user the needed flexibility to handle many graphic processes which could not be as efficiently handled without this capability.

GPGSY, the implemented subset of GPGL, contains only five of the above required functions. The additional five functions should be added to GPGSY if the system is going to be used as an effective graphic system. These additional functions can be added without any great difficulty, but

the storage requirements would be significantly increased. In order to provide the user-defined function capability, the necessary teletype functions would have to be implemented. These include the user-defined instruction set, the teletype-system commands, the teletype-editor commands and the keyboard mode command. Implementing these functions would be a more difficult task than completing the basic requirement subset. The implementation of these functions and the user-defined functions, which would be created, would greatly increase the storage requirements of the system. In order to develop GPGSY into a true interactive, general purpose graphic system, these additional functions should be implemented, even though these changes are costly in storage and man hours.

The tri-level hierarchy of GPGSY provides a capability which is adequate for many applications. The cost of overhead can easily be reduced to 110 memory cells per picture (where three subpictures and 24 images are in a picture). The ease provided in manipulating the images and subpictures, which form the picture, is well worth this cost. Considering the trade-off between the necessary overhead in implementing hierarchial levels and the flexibility provided, the selection of three hierarchial levels appears to be excellent.

```
        EXPUNGE
        TITLE GPGSY
        ENTRY GPGSY

        [ EXTERNAL ENTRIES- $ØFST:PRINTS THE STRING ØN TELETYPE WHICH FØLLØWS THE CALL
        [                  - $ICC:FETCHES A CHAR. INPUT BY TELETYPE (IN AR)
        [                  - $WT1:HANDLES THE BACKGRØUND,WHILE $ICC HANDLES FØREGRØUND
        [ ALL IN AMRMX (MØNITØR)


        [ INITIALIZATIØN
        [ DBLK1- HEAD ØF DIRECTØRY
        [ RØUTINE ENABLES SCØPE,AVG,FRAMECLØCK,FUNCTIØN SWITCHES

        GPGSY:          0
                        ARMD            SAVEAR          [SAVE THE AR REGISTER CØNTENTS
                        MDAR'F          FCLER
                        ARMD            CLKPV
                        MDAR'F          DBLK1
                        ARMD            DBLK            [LØAD LØC ØF HEAD ØF DIRECTØRY IN DBLK
                        MD10'L
                        60400VH
                        MDIC'Ø'L
                        00040VH
                        MD11            SCAL            [SET SCALE
                        MD06            INTENS          [SET INTENSITY
                        MD10'Ø'L
                        1000VH


        [ DRAW TEXT   RØUTINE

        [ FFLAG-FLAG SET TØ LØAD DTEXT WITH ENTRY ADDRESS
        [ IDFLG-FLAG TØ TELL CLØCK IMAGE IS DRAWN
        [ CURFG-FLAG SET TØ DRAW CURSØR
        [ FLG1-FLAG USED TØ KEEP FRØM GETTING MULTIPLE HITS ØN DESIGNATING PØINTS
        [ LPFLG-FLAG USED TØ KEEP LIGHT PEN ØFF 1 SEC.
        [ LPCNT-CYCLE CØUNTER TØ KEEP LIGHT PEN ØFF
        [ INCTXT-INCREMENTS FETCH FØR LCG

        [ RØUTINE DRAWS TEXT FØR FUNCTIØN ØNE AT A TIME

        DTEXT:          0
                        MDAR            FFLAG
                        JPLS            .+6
                        MDAR            GPGSY
                        MDAR'A          MASK5
                        MDAR'Ø          MASK8
                        ARMD            DTEXT
                        ARMD'Ø          FFLAG
                        ARXØ'F
                        ARMD            IDFLG
        [DRAW TEXT RØUTINE CØNT.

                        MDAR            CURFG
                        JPLS            .+2
                        JUMP            DTEXT1
                        SSAR'F
                        JPAN            DFSPT           [ IF NEGATIVE JUMP TØ DESIGNATE PØINT
                        ARXØ'F
                        ARMD            FLG1

        DTEXT1:         0
                        MDAR'F          LPLER
                        ARMD            LPNPV
                        MDAR            LPFLG
                        JPLS            SKIP
                        MDAR            LPCNT
                        MDXØ            LPMASK          [ MASK TØ PERMIT LIGHT PEN TURN ØN
                        JPLS            SKIP1
                        ARXØ'F
                        ARMD            LPCNT
                        MDAR            ØNE
                        ARMD            LPFLG

        SKIP:           MD10'Ø'L
                        20VH                            [ TURN ØN LIGHT PEN AGAIN
        SKIP1:          MD10'A          MASK12          [ TURN ØFF AVG
                        MD07            ZERØ
                        MDAR'F          DRTEXT
                        MDAR'A          MASK5
                        ARMD            INCTXT
                        MDAR'F          DRTEXT
                        ARMD            77735           [ DRTEXT IS TEXT DISPLAY LIST
                        MDAR'F          TXLER
                        ARMD            77736
                        MDAR'F          TXLER
                        ARMD            77737
                        MDIC'A          CM14
                        MDIC'Ø          TEN             [ DRAW TEXT
                        MDAR            SAVEAR
                        MDIR            DTEXT
```

```
[ DRAW VECTØRS RØUTINE

[ FUNCTIØN FLAGS-IF SET GØ TØ RØUTINES FØR ACTIØN REQ
[ CURFG-FLAG SET TØ DRAW CURSØR
[ BCNT-CØUNT TØ DETERMINE WHICH IMAGE IS TØ BE DRAWN
[ TBCNT-TØTAL WHEN ALL IMAGES DRAWN
[ CØNT-10,20,30 DEPENDING ØN WHICH SUBPIC
[ FRFG1-FLAG TØ SHØW IN SUBPIC2
[ FRFG2-FLAG TØ SHØW IN SUBPIC3
[ IMCFG-FLAG ØNCE SET DIRECTS THE PRØGRAM FLØW THRØUGH IMCLØ

[ BASIC VECTØR DRAWING RØUTINE,JUMP ØUT TØ HANDLE FUNCTIØN ACTIØNS        AND -
[ RETURN.LØADS NECCESSARY REGISTERS BY LØØPING IN TT FØR EACH IMAGE WHICH -
[ HAS SØMETHING IN IT TØ DRAW.

DRVEC:          JUMP          .
                MDIC'A        CM14          [ TURN ØFF LCG
                MDAR          FRAMEFG
                JSLS          FRAM1
                MDAR          TTYFG
                JSLS          TTY1
                MDAR          CURFG
                JSLS          PTRAC         [ CURSØR AND PEN TRACKING RØUTINE
                MDAR'F        EØLER
                ARMD          EØLPV
                MD10'Ø'L
                6D400JH                     [TURN ØN AGAIN
                MDAR          TRANFG
                JSLS          TRAN1
                MDAR          ZØØMFG
                JSLS          ZØØM1
                MDAR          DASHFG
                JSLS          DASH1
                MDAR          ERASEFG
                JSLS          ERASE1
                MDAR          NAMEFG
                JSLS          NAME1
                MDAR          REFG
                JSLS          REF1
                MDAR          DATA1
                MDXØ          MZERØ         [ NØ WØRDS IN DISPLAY LIST JUMP SKIP2
                JPLS          .+2
                JUMP          SKIP2
                MDAR'L
                M005          DATA1-1
                ARMD          77756
[ DRAW VECTØR RØUTINE CØNT.

TT:             ARXØ'F                      [LØØP THAT LØADS REGISTERS AND DRAWS
                ARMD          EØLFG
                MDAR          BCNT
                MDXØ          CØNT
                JPLS          .+2
                JUMP          SKIP2
                MDAR          BCNT
                ARLS          2
                NØØP
                MDAE          BCNT
                MDAE          BCNT
                ARMD          TEMP4
                MDAR'F        DBLK1
                MDAE          TEMP4
                ARMD          TEMP4
                MDAR'I        TEMP4
                MDXØ          MZERØ
                JPLS          V1
                MDAR          FRFG2
                JPLS          SKIP2
                MDAR          FRAMEFG
                JSLS          FRAM3
                MDAR          FRFG1
                JPLS          TT
                JUMP          SKIP2
V1:             MDAR          IMCFG
                JPLS          IMCL1
V2:             MD11'I'X      TEMP4
                MD06'I'X      TEMP4         [LØAD INTENSITY FØR THIS IMAGE
                MD07'I'X      TEMP4         [LØAD DXDY FØR THIS IMAGE
                MDAR'X        TEMP4
                MD10'Ø'I      TEMP4         [IF DASHMASK IN SET DASH MØDE
V3:             MDAR'X        BCNT
                MDIR'X        77756         [ DRAW VECTØRS
                MDAR'N        EØLFG
                JPAN          .-1
                MD10'A        MASK14
                JUMP          TT
SKIP2:          MDAR          BCNT
                ARMD          TBCNT
                ARXØ'F
                ARMD          BCNT
                ARMD          FRFG1
                ARMD          FRFG2
                MDAR          ØNE
                ARMD          IØFLG
                MDAR          SAVAR
                MDIR          DRVEC
```

```
        [ FRAME FUNCTIØN

        [ FFG1-FLAG SET WHEN BEEN THRØUGH RØUTINE ØNCE AFTER FIRST LIGHT PEN HIT
        [ FFG2-FLAG SET WHEN BEEN THRØUGH RØUTINE ØNCE AFTER SECØND LIGHT PEN HIT
        [ WCØNT-WØRD CØUNT CURRENT SUBPIC
        [ TWCNT-TØTAL WØRD CØUNT ØF SUBPIC BEING CLØSED AND ANY PREVIØUS SUBPICS
        [ CØNT1-CØUNTER TØ EXIT LØØP
        [ ICFG-FLAG SET IN WBLØP WHICH SHØWS ALL IMAGES IN THE SUBPIC ARE CLØSED
        [ TBCN1-CØUNT ØF IMAGES IN FIRST SUBPIC
        [ TBCN2-CØUNT ØF SUBPICS + 10 IN SECØND SUBPIC

        [ RØUTINE CLØSES ØUT ØNE SUBPIC AND ØPENS THE NEXT ØNE BY STØRING THE WØRD
        [ CØUNT ØF THE ØLD SUBPIC AND IMAGE CØUNT THAT IS USED FØR THE ØFFSET TØ
        [ THE DIRECTØRY.
       FRAM1:          JUMP          .
                       ARXØ'F
                       ARMD          ICFG
                       MDAR          FRAMEFG
                       MDXØ          ØNE
                       JPLS          FR1
                       MDAR          FFG1
                       JPLS          END2
                       MDAR          ØNE
                       ARMD          FFG1
                       JPSR          $ØFST          [ PRINT VIA TELETYPE STRING
       STRING '
         SUBPIC 1 CLØSED, SUBPIC 2 ØPENED
       '
       F1:             MDAR          WCØNT          [ FETCH WØRD CØUNT ØF CURRENT SUBPIC
                       ARMD          WCNT1
                       ARMD          TWCNT
                       MDAR          TBCNT
                       ARMD          TBCN1
                       ARXØ'F
                       ARMD          WCØNT
                       MDAR          DBLK           [ADDRESS ØF THE HEAD ØF DIRECTØRY
                       MDAE          TWØ
                       ARMD          TEMP1
                       MDAR          TWEN
                       ARMD          CØNT
       ØVER:           MDAR          ZERØ           [ LØØP WHICH ZERØES INTENSITY
                       ARMD'I        TEMP1
                       MDAR'X        CØNT1
                       MDAR          TEMP1
                       MDAE          SIX
                       ARMD          TEMP1
                       MDAR          CØNT1
                       MDXØ          TEN
                       JPLS          ØVER
                       ARXØ'F
                       ARMD          CØNT1
                       JUMP          END2
       [ FRAME FUNCTIØN CØNT.

       FR1:            MDAR          FRAMEFG        [ THIS PØRTIØN HANDLES CLØSING SUBPIC2 -
                       MDXØ          TWØ            [ AND ØPENING SUBPIC3.
                       JPLS          FR2
                       MDAR          FFG2
                       JPLS          END2
                       MDAR          ØNE
                       ARMD          FFG2
                       JPSR          $ØFST          [ PRINT STRING THAT FØLLØWS
       STRING '
         SUBPIC 2 CLØSED, SUBPIC 3 ØPENED
       '
       F2:             MDAR          WCØNT
                       ARMD          WCNT2
                       MDAE          TWCNT
                       ARMD          TWCNT
                       MDAR          TBCNT
                       ARMD          TBCN2
                       ARXØ'F
                       ARMD          WCØNT
                       MDAR'F        DØLK21
                       MDAE          TWØ
                       ARMD          TEMP1
                       MDAR          THIR
                       ARMD          CØNT
                       JUMP          ØVER
       FR2:            JPSR          $ØFST          [PRINT STRING THAT FØLLØWS
       STRING '
         ALL FRAMES FILLED
       '
                       MDAR'F        DATA1
                       MDAE          TWCNT
                       MDAE          WCØNT
                       MDAE          ØNE
                       ARMD          TEMP5
                       MDAR          MASKØ
                       ARMD'I        TEMP5
                       MDAR          TWCNT
                       MDAE          TWØ
                       ARMD          TWCNT
       END2:           MDIR          FRAM1
```

```
[ FRAME 3 FUNCTIØN

[ RØUTINE USED TØ CHANGE BCNT(IMAGE CØUNT) TØ THE CØRRECT FIGURE
[ IN ØRDER TØ CØMPUTE THE CØRRECT ØFFSET TØ THE DIRECTØRY BECAUSE
[ ALL TEN IMAGES PER SUBPIC MIGHT NØT BE USED.

FRAM3:          JUMP            .
                MDAR            BCNT
                MDAE'N          TEN
                JPAN            .+2
                JUMP            FR5
                MDXØ            MZERØ
                JPLS            .+2
                JUMP            FR5
                MDAR            ØNE
                ARMD            FRFG1
                MDAR            TEN
                ARMD            BCNT
                MDIR            FRAM3
FR5:            MDAR            FRAMEFG
                MDXØ            TWØ
                JPLS            FR6
                MDAR            TWEN
                ARMD            BCNT
                MDAR            ØNE
                ARMD            FRFG1
                ARMD            FRFG2
                MDIR            FRAM3
FR6:            ARXØ'F
                ARMD            FRFG1
                MDIR            FRAM3
[ NAME FUNCTIØN

[ TYPEFG.SET TØ KEEP FRØM PRINTING THE TELETYPE MESSAGE EACH ENTRY
[ NAMER.CELL WHERE NAME IS FØRMED
[ CNTER.CØUNTER TØ CHECK ØN NUMBER ØF CHARS. ENTERED
[ WBADR.ADRESS ØF HEADER ØF IMAGE DIRECTØRY ØPEN
[ ICFG-FLAG SET IN WBLØP WHICH SHØWS ALL IMAGES IN SUBPIC ARE CLØSED

[ RØUTINE CALLS FØR NAME ØF IMAGE TØ BE INPUTTED,AND STØRES IT -
[ IN HEADER ØF IMAGE DIRECTØRY

NAME1:          JUMP            .
                MDAR            TYPEFG
                JPLS            AGAIN
                MDAR            ØNE
                ARMD            TYPEFG
                JPSR            $ØFST           [ PRINT INSTRUCTIØNS BY TELETYPE
STRING '
  INPUT UP TØ 5 CHARS.
'
AGAIN:          MDAR'L
                JUMP            WAIT1           [ JUMP TØ WAIT RØUTINE LØADED IN $WT1
                ARMD            $WT1
                JPSR            $ICC            [ FETCH TELETYPE CHAR.(IN AR ØN RETURN)
                ARMD            TEMP1
                MDXØ            FIFT
                JPLS            .+2
                JUMP            ØVER1
                MDAR            CNTER
                MDXØ            ZERØ
                JPLS            N1
                MDAR            TEMP1
                ARLS            30
                NØØP
                MDAR'Ø          NAMER
                ARMD            NAMER
                MDAR'X          CNTER
                JUMP            AGAIN
N1:             MDAR            CNTER
                MDXØ            ØNE
                JPLS            N2
                MDAR            TEMP1
                ARLS            22
                NØØP
                MDAR'Ø          NAMER
                ARMD            NAMER
                MDAR'X          CNTER
                JUMP            AGAIN
```

```
[ NAME FUNCTIØN CØNT.

N2:             MDAR            CNTER
                MDAR            CNTER
                MDXØ            TWØ
                JPLS            N3
                MDAR            TEMP1
                ARLS            14
                NØØP
                MDAR'Ø          NAMER
                ARMD            NAMER
                MDAR'X          CNTER
                JUMP            AGAIN

N3:             MDAR            CNTER
                MDXØ            THREE
                JPLS            N4
                MDAR            TEMP1
                ARLS            6
                NØØP
                MDAR'Ø          NAMER
                ARMD            NAMER
                MDAR'X          CNTER
                JUMP            AGAIN

N4:             MDAR            CNTER
                MDXØ            FØUR
                JPLS            N5
                MDAR            TEMP1
                MDAR'Ø          NAMER
                ARMD            NAMER
                MDAR'X          CNTER
                JUMP            AGAIN
N5:             JPSR            $ØFST           [ TØØ MANY CHARS. ENTERED
STRING '
  ØNLY FIRST FIVE CHAR. ACCEPTED
'
ØVER1:          JPSR            WBLØP
                MDAR            ICFG
                JPLS            IMCLØ
N6:             MDAR            NAMER
                ARMD'I          WBADR
                MDAR            ICFG
                JPLS            FINIS
                MDAR            WBADR
                MDAL            FIVE
                ARMD            TEMP3
                MDAR            WCØNT
                ARMD'I          TEMP3
                JUMP            FINIS
[ NAME FUNCTIØN CØNT.

ERR1:           JPSR            $ØFST           [ ERRØR ALL IMAGES USED
STRING  '
  ALL IMAGES USED THIS RUBRIC
'
FINIS:          JPSR            $ØFST           [ IMAGE CLØSED MSG. PRINTED
STRING '
  IMAGE CLØSED,NEW IMAGE ØPENED
'
                ARXØ'F
                ARMD            NAMER
                ARMD            NAMEFG
                ARMD            CNTER
                ARMD            TYPEFG
                MDIR            NAME1
```

```
[ TELETYPE FUNCTION

[ PTCORD1-COORDINATES OF POINT ONE
[ PTCORD2-COORDINATES OF POINT TWO
[ PTCNT-POINT COUNTER USED TO GO TO CORRECT ENTRY
[ TTYCNT-TELETYPE INPUT COUNTER
[ LFG1-USED IN DESPT TO SHOW TELETYPE END POINT
[ TRANFG1-FLAG USED IN TRAN TO SHOW POINT RECEIVED
[ ERRFG- FLAG SET IN CHECK ROUTINE TO SHOW ERROR IN TTY

[ ROUTINE PERMITS TELETYPE ENTRY INSTEAD OF NORMAL LIGHT PEN ENTRY -
[ OF POINTS FOR LINE,TRAN,REF.SENDS LINE END POINTS TO DESPT TO -
[ LOAD INTO THE DISPLAY LIST AND LOAD IMAGE DIRECTORY.

TTY1:           JUMP            .
                JPSR            $OFST           [ PRINT INSTRUCTIONS BY TELETYPE
STRING '
  INPUT POINT (10 OCTAL DIGITS)
'
                MDAR            REFG
                JPLS            RCOM
                MDAR            TRANFG
                JPLS            TRATY
AGAIN2:         MDAR'L
                JUMP            WAIT1           [ LOAD JUMP TO WAIT ROUTINE IN $WT1
                ARMD            $WT1
                JPSR            $ICC            [ FETCH TELETYPE CHAR.
                ARMD            TEMP1
                MDAR            LINEFG
                JPLS            .+2
                JUMP            .+5
                MDAR            TEMP1
                MDXO            FIVE
                JPLS            .+2
                JUMP            FINI1
                MDAR            TEMP1
                MDXO            FIFT
                JPLS            SKIP22
                MDAR            TTYCNT
                MDXO            TWELVE
                JPLS            .+2
                JUMP            .+2
                JUMP            ERR2
                ARXO'F
                ARMD            TTYCNT
                MDAR            REFG
                JPLS            RCOMP
                MDAR            TRANFG
                JPLS            TCOMP
                JUMP            COMP

[ TELETYPE FUNCTION CONT.

SKIP22:         JPSR            CHECK           [ CHECK CHAR.TO SEE IF DIGIT
                MDAR            ERRFG
                JPLS            ERR2            [ ERROR SO JUMP TO ERR2
                MDAR            TEMP1
                MDAR'A          SEVEN
                ARMD            TEMP1
                MDAR            PTCNT
                JPLS            SKIP23
                MDAR            TEMP1
                MDAR'O          PTCORD1
                ARMD            PTCORD1
                MDAR'X          TTYCNT
                MDXO            TWELVE
                JPLS            .+2
                JUMP            T1
                MDAR            PTCORD1
                ARLS            3
                ARMD            PTCORD1
T1:             JUMP            AGAIN2

SKIP23:         MDAR            TEMP1
                MDAR'O          PTCORD2
                ARMD            PTCORD2
                MDAR'X          TTYCNT
                MDXO            TWELVE
                JPLS            .+2
                JUMP            T2
                MDAR            PTCORD2
                ARLS            3
                ARMD            PTCORD2
T2:             JUMP            AGAIN2

COMP:           MDAR            PTCNT
                JPLS            COMP1
                MDAR'X          PTCNT
T3:             JPSR            $OFST
STRING '
  INPUT NEXT END POINT(10 OCTAL DIGITS) OR . TO END
'
              - ARXO'F
                ARMD            PTCORD2
                JUMP            AGAIN2

COMP1:          MDAR            ONE
                ARMD            LFG1
                MDAR'X          PTCNT
                JUMP            JU
```

```
[ TELETYPE FUNCTIN CØNT.

FINI1:          ARXØ'F
                ARMD            LINEFG
                ARMD            TTYFG
                ARMD            PTCØRD1
                ARMD            PTCØRD2
                ARMD            PTCNT
                MDIR            TTY1

RCØM:           MDAR            ØNE             [ THIS PØRTIØN HANDLES REF FUNCTIØN
                ARMD            PTCNT
                JUMP            AGAIN2
RCØMP:          MDAR            PTCØRD2
                MDAR'A          MASK6
                ARMD            NUMB2
                ARXØ'F
                ARMD            REFG1
                JUMP            FINI1

TRATY:          MDAR            ØNE             [ THIS PØRTIØN HANDLES TRAN FØNCTIØN
                ARMD            PTCNT
                JUMP            AGAIN2

TCØMP:          MDAR            PTCØRD2
                MDAR'A          MASK6
                ARMD            NUMB2
                ARXØ'F
                ARMD            TRANFG1
                JUMP            FINI1

ERR2:           MDAR            LINEFG          [ ERRØR HANDLING PART
                JPLS            .+2
                JUMP            ERR3
                JPSR            $ØFST           [ PRINT STRING FØR LINE ERRØR
STRING '
  ERRØR,INPUT FIRST END PØINT AGAIN (10 ØCTAL DIGITS) AND C/R
'
                ARXØ'F
                ARMD            PTCNT
                JUMP            ERR4

ERR3:           JPSR            $ØFST           [ PRINT STRING FØR TRAN AND REF
STRING '
  ERRØR,INPUT PØINT AGAIN (10 ØCTAL DIGITS) AND C/R
'
                MDAR            ØNE
                ARMD            PTCNT
ERR4:           ARXØ'F
                ARMD            ERRFG
                ARMD            TTYCNT
                JUMP            AGAIN2
[ ERASE FUNCTIØN

[ RØUTINE SETS LIGHT PEN PIVØT FØR ERASE,TURNS LIGHT PEN ØN              ,.
[ AND GIVES APPRØPRIATE INSTRUCTIØNS TØ USER.

ERASE1:         JUMP            .
                MDAR'F          ELPLER
                ARMD            LPNPV
                MDIC'Ø'L
                20JH
                MDAR            TYPEFG
                JPLS            FINI2
                JPSR            $ØFST
STRING '
  SELECT IMAGE TØ ERASE WITH LIGHT PEN
'
                MDAR            ØNE
                ARMD            TYPEFG
FINI2:          MDIR            ERASE1


[ ERASE LIGHT PEN HANDLER

[ BCNT-CØUNTR WHICH SHØWS WHAT IMAGE IS CURRENTLY BEING DRAWN
[ TWCNT-TØTAL WØRD CØUNT IN DISPLAY LIST WHEN LAST SUBPIC CLØSED
[ DATA1-HEADER FØR DISPLAY LIST
[ DBLK-ADDRESS ØF HEADER FØR DIRECTØRY

[ RØUTINE LØCATES WHICH IMAGE IS BEING REFRESHED AT TIME ØF PICK -
[ BY BCNT AND ERASES THE ENTIRE IMAGE

ELPLER:         0
                ARMD            SAR1
                MDAR            DATA1
                MDXØ            MZERØ
                JPLS            E1
                JUMP            END3
E1:             MDAR            BCNT
                MDXØ            ØNE
                JPLS            E2
                MDAR'F          DATA1
                ARMD            TEMP5
                JUMP            AGAIN3

[ ERASE LIHT PEN HANDLER

E2:             MDAR            BCNT
                ARLS            2
                NØØP
                MDAE            BCNT
                MDAE            BCNT
                MDAE'N          SIX
                ARMD            TEMP1
```

```
        [ ERASE LIGHT PEN HANDLER CONT.

                        MDAR            DBLK
                        MDAE            TEMP1
                        MDAE'N          ONE
                        ARMD            TEMP1
                        MDAR'I          TEMP1
                        ARMD            TEMP4
                        MDAR'X          TEMP1
                        MDAR'F          DBLK21
                        MDXO            TEMP1
                        JPLS            .+4
                        MDAR            TWCNT
                        ARMD            TEMP4
                        JUMP            E3
                        MDAR'F          DBLK31
                        MDXO            TEMP1
                        JPLS            .+4
                        MDAR            TWCNT
                        ARMD            TEMP4
                        JUMP            E3
                        MDAR            FRAMEFG
                        JPLS            .+2
                        JUMP            .+5
                        MDAR            TEMP4
                        MDAE            TWCNT
                        ARMD            TEMP4
                        JUMP            E3
                        MDAR            TEMP4
                        ARMD            TEMP4
        E3:             MDAR'F          DATA1
                        MDAE            TEMP4
                        ARMD            TEMP5

        AGAIN3:         MDAR'I'H        TEMP5
                        MDAR'A          ONE
                        JPLS            E4
                        MDAR'I          TEMP5
                        MDAR'A          MASK10
                        ARMD'I          TEMP5
                        MDAR'X          TEMP5
                        JUMP            AGAIN3
        E4:             MDAR'I          TEMP5
                        MDAR'A          MASK10
                        ARMD'I          TEMP5
                        MDIO'A          MASK2
        END3:           ARXO'F
                        ARMD            TYPEFG
                        ARMD            ERASEFG
                        MDAR            SAR1
                        JUMP'I          ELPLER
        [REFFRENCE POINT FUNCTION

        [ NUMB1-NUMBER TO SUBTRACT TO BE SUBTRACTED IN SUB2
        [ NUMB2-NUMBER WHICH NUMB1 IS SUBTRACTED FROM IN SUB2
        [ DXDY-LOC WHERE DIFFERENCE IN X (0-14 BITS) AND Y (15-29) IS STORED
        [ MOVFG- SET IF DISPLAY LIST WORD WAS A MOVE
        [ REFPT- CELL IN WHICH REFFRENCE POINT IS STORED
        [ WBADR-ADRESS OF HEADER OF OPEN IMAGE

        [ ROUTINE LOADS SUBTRACTS OLD REFERENCE POINT FROM THE NEW ONE DESIGNATED -
        [ AND LOADS RESULT IN IMAGE DIRECTORY AS OFFSET INCREMENT(TO BE LOADED IN -
        [ D7 REGISTER) AND SUBTRACTS SAME RESULT FROM EACH WORD IN IMAGE DISPLAY LIST.
        [ LOADS NEW REFERENCE POINT IN REFPT

        REF1:           JUMP            .
                        MDAR            TTYFG
                        JSLS            TTY1
        RCOMP1:         MDAR            REFG1
                        JPLS            END
                        MDAR            ICFG
                        JPLS            IMCLO
                        MDAR            REFPT
                        ARMD            NUMB1
                        JPSR            SUB2
                        MDAR            NUMB1
                        ARMD            DXDY
                        MDAR            NUMB2
                        ARMD            REFPT
                        JPSR            WBLOP           [ JUMP TO FIND OUT OPEN IMAGE
                        MDAR            WBADR
                        MDAE'N          ONE
                        ARMD            TEMP1
                        MDAE'N          DBLK            [ SUBTRACT TO HEAD OF DIRECTORY ADDRESS
                        JPAN            .+2
                        JUMP            .+4
                        ARXO'F
                        ARMD            TEMP2
                        JUMP            RO
                        MDAR'I          TEMP1
                        ARMD            TEMP2
                        MDAR            FRAMEFG
                        JPLS            .+2
                        JUMP            RO
                        MDAR'X          TEMP1
                        MDAR'F          DBLK21
                        MDXO            TEMP1
                        JPLS            .+2
                        JUMP            .+3
                        MDAR'F          DBLK31
                        MDXO            TEMP1
                        JPLS            .+4
```

```
        [ REFERENCE POINT FUNCTION CONT.

                MDAR            TWCNT
                ARMD            TEMP2
                JUMP            R0
                MDAR            TEMP2
                MDAE            TWCNT
                ARMD            TEMP2

        R0:     MDAR'F          DATA1
                MDAE            TEMP2
                ARMD            TEMP2
        R1:     MDAR            DXDY
                ARMD            NUMB1
                MDAR'I'H        TEMP2
                MDAR'A          ONE
                JPLS            R2
                MDAR'I          TEMP2
                MDAR'A          ONE
                JPLS            .+3
                MDAR            ONE             [WORD IN DISPLAY LIST IS MOVE,SET MOVFG
                ARMD            MOVFG
                MDAR'I          TEMP2
                MDAR'A          MASK6
                ARMD            NUMB2
                JPSR            SUB2
                MDAR            MOVFG
                MDXO            ONE
                JPLS            .+3
                MDAR            NUMB1
                JUMP            .+3
                MDAR            NUMB1
                MDAR'O          ONE
                MDAR'A          MASK7           [ MASK7=7777677777
                ARMD'I          TEMP2
                ARXO'F
                ARMD            MOVFG
                MDAR'X          TEMP2
                JUMP            R1
        R2:     MDAR            DXDY            [ THIS PORTION HANDLES WORD WITH EOL -
                ARMD            NUMB1           [ BIT SET(LAST WORD CURRENTLY IN IMAGE)
                MDAR'I          TEMP2
                MDAR'A          MASK6
                ARMD            NUMB2
                JPSR            SUB2
                MDAR            NUMB1
                MDAR'O          C1H1
                ARMD'I          TEMP2
                MDAR            WRADR
                MDAE            THREE
                ARMD            TEMP1
                MDAR            REFPT
                ARMD'I          TEMP1
        [ REFERENCE POINT CONT.

        R3:     ARXO'F
                ARMD            REFG
                ARMD            TTYFG
                MDAR            ONE
                ARMD            REFG1
        END:    MDIR            REF1


        [ CHECK FOR DIGIT IN CODE

        [ ROUTINE CHECKS TELETYPE INPUT AND MAKES SURE IT IS A DIGIT
        [ SETS ERRFG IF AN ERROR IS DETECTED

        CHECK:  JUMP            .
                MDAR            TEMP1
                MDAR'A'L
                77770
                MDXO            TWEN
                JPLS            .+2
                MDIR            CHECK
                MDAR            ONE
                ARMD            ERRFG
                MDIR            CHECK
```

```
        [ TRANSLATION FUNCTION

        [ TRANFG1-FLAG WHEN ZERO SHOWS A POINT HAS BEEN DESIGNATED
        [ NUMB1-NUMBER TO SUBTRACT IN SUB2
        [ NUMBE2-NUMBER TO BE SUBTRACTED FROM IN SUB2
        [ WBADR-HEADER OF IMAGE DIRECTORY OPEN

        [ ROUTINE HAS SUB2 SUBTRACT OLD REFERENCE POINT FROM POINT DESIGNATED -
        [ AS TRANSLATION DIRECTION AND DISTANCE.PROGRAM ENTERS EVERY CYCLE AFTER
        [ TRAN HIT SO IF POINTS NOT DESIGNATED YET,JUMP TO END1.

        TRAN1:          JUMP            .
                        MDAR            TTYFG
                        JSLS            TTY1
        TRAN2:          MDAR            TRANFG1
                        JPLS            END1
                        MDAR            REFPT
                        ARMD            NUMB1
                        JPSR            SUB2
                        JPSR            WBLOP
                        MDAR            ICFG
                        JPLS            IMCLO
        TRAN3:          MDAR            WBADR
                        MDAE            THREE
                        ARMD            TEMP2
                        MDAR            NUMB1
                        ARMD'I          TEMP2
                        ARXO'F
                        ARMD            TRANFG
                        MDAR            ONE
                        ARMD            TRANFG1
        END1:           MDIR            TRAN1



        [SUBTRACT TWO POINT ROUTINE

        [ NUMB1-NUMBER TO SUBTRACT
        [ NUMB2-NUMBER SUBTRACTED FROM

        [ ROUTINE SUBTRACTS TWO POINTS,HALF WORD AT A TIME,UPPER HALF IS X -
        [ COORD. AND LOWER HALF THE Y COORD.

        SUB2:           JUMP            .
                        MDAR            NUMB1
                        MDAR'A          MASK3           [ MASK3=0000077776
                        ARMD            TEMP3           [STORE RP
                        MDAR            NUMB2
                        MDAR'A          MASK3           [AND MASK3 WITH LP1
                        ARMD            TEMP4           [STORE IN TEMP4
                        MDAE'N          TEMP3
                        ARMD            TEMP3
                        MDXO            MZERO
                        JPLS            .+3
                        ARXO'F
                        ARMD            TEMP3
                        MDAR            TEMP3
                        MDAR'A          MASK3
                        ARMD            TEMP3
                        MDAR            NUMB1
                        ARRS            17              [RIGHT SHIFT 15
                        NOOP
                        ARMD            TEMP4           [STORE RP (0-14) IN TEMP (15-29)
                        MDAR            NUMB2
                        ARRS            17
                        NOOP
                        ARMD            TEMP5
                        MDAE'N          TEMP4
                        ARMD            TEMP4
                        MDXO            MZERO
                        JPLS            .+3
                        ARXO'F
                        ARMD            TEMP4
                        MDAR            TEMP4
                        ARLS            17
                        NOOP
                        MDAR'A          MASK4           [ MASK4=7777700000
                        MDAR'O          TEMP3           [ OR DX (0-14) AND DY (15-29)
                        ARMD            NUMB1
                        MDXO            MZERO
                        JPLS            .+3
                        ARXO'F
                        ARMD            NUMB1
                        MDIR            SUB2


```

```
        [ ZCNTER-CØUNTER TØ CØUNT INPUT DIGITS
        [ FAC1-CELL WHERE INPUT NUMBER FØRMED
        [ ERRFG-FLAG SET IN CHECK IF ERRØR
        [ WBADR-ADRESS ØF HEADER ØF DIRECTØRY ØF IMAGE ØPEN

        [ RØUTINE ACCEPTS TELETYPE DIGITS TØ SET SCALE IN AVS FRØM 0-1
        [ SENDS INPUTTED CHARS. TØ CHECK FØR VERIFICATIØN,IF ERRØR USER -
        [ MUST INPUT AGAIN

        ZØØM1:          JUMP            .
                        JPSR            $ØFST
        STRING '
          INPUT UP TØ 5 ØCTAL DIGITS,NEGATIVE DIMINISHES
        '
        AGAIN1:         MDAR'L
                        JUMP            WAIT1
                        ARMD            $WT1
                        JPSR            $ICC
                        ARMD            TEMP1
                        MDXØ            FIFT
                        JPLS            Z1
                        MDAR            FIVE
                        MDAE'N          ZCNTER
                        JPAN            ZØØM2
                        MDAR            FAC1
                        ARRS            3
                        JUMP            ZØØM2
        Z1:             MDAR            ZCNTER
                        MDXØ            FIVE
                        JPLS            .+2
                        JUMP            ERRØR
                        JPSR            CHECK
                        MDAR            ERRFG
                        JPLS            ERRØR           [IF ERRØR FLAG SET JUMP TØ ERRØR
                        MDAR            TEMP1
                        MDAR'A          SEVEN
                        MDAR'Ø          FAC1
                        ARMD            FAC1
                        MDAR'X          ZCNTER
                        MDXØ            FIVE
                        JPLS            .+2
                        JUMP            AGAIN1
                        MDAR            FAC1
                        ARLS            3
                        ARMD            FAC1
                        JUMP            AGAIN1

        [ ZØØM FUNCTIØN CØNT.

        ZØØM2:          MDAR            FAC1
                        ARLS            17
                        NØØP
                        ARMD            FAC1
                        JPSR            WBLØP
                        MDAR            ICFG
                        JPLS            IMCLØ
        Z2:             MDAR            WBADR
                        MDAE            ØNE
                        ARMD            TEMP3
                        MDAR'I          TEMP3
                        MDAE            FAC1
                        ARMD            FAC1
                        MDAR            ICFG
                        JPLS            Z4
                        MDAR            MXSCL
                        MDAE'N          FAC1
                        JPAN            .+2
                        JUMP            Z3
                        MDAR            MXSCL
                        ARMD'I          TEMP3
                        JUMP            Z5
        Z3:             MDAR            FAC1
                        JPAN            .+2
                        JUMP            Z4
                        MDAR            ZERØ
                        ARMD'I          TEMP3
                        JUMP            Z5
        Z4:             MDAR            FAC1
                        ARMD'I          TEMP3
        Z5:             ARXØ'F
                        ARMD            ZCNTER
                        ARMD            FAC1
                        ARMD            ZØØMFG
                        MDIR            ZØØM1

        ERRØR:          JPSR            $ØFST           [ ERRØR SØ PRINT FØLLØWING STRING
        STRING '
          INPUT UP TØ 5 ØCTAL DIGITS (0-37777) AND C/R
        '
                        ARXØ'F
                        ARMD            ERRFG
                        ARMD            ZCNTER
                        ARMD            FAC1
                        JUMP            AGAIN1

        WAIT1:                          0               [ DØ NØTHING LØØP WAITING FØR $ICC -
                        JUMP            .-1             [ TØ FETCH A TELETYPE CHAR.
```

```
[ DASH FUNCTIØN

[ WBADR-ADDRESS ØF HEAD ØF DIRECTØRY ØF IMAGE ØPEN

[ RØUTINE LØADS DAHMASK IN IMAGE DIRECTØRY ØF ØPEN IMAGE AND RESETS DASHFG

DASH1:          JUMP            .
                JPSR            WBLØP
                MDAR            ICFG
                JPLS            IMCLØ
D1:             MDAR            WBADR
                MDAE            FØUR
                ARMD            TEMP1
                MDAR            DASHMASK
                ARMD'I          TEMP1
                ARXØ'F
                ARMD            DASHFG
FINI3:          MDIR            DASH1

[ IMAGE CLØSED RØUTINE

[ ICFG-FLAG WHICH IS SET IN WBLØP WHICH SHØWS ALL IMAGES ARE CLØSED
[ IMCFG-FLAG ØNCE SET DIRECTS PRØGRAM FLØW THRØUGH IMCLØ
[ ICFG1-FLAG THAT SHØWS SUBPIC1 IS MANIPULATED
[ ICFG2-FLAG THAT SHØWS SUBPIC2 IS MANIPULATED
[ ICFG3-FLAG THAT SHØWS SUBPIC3 IS MANIPULATED
[ SUBP1,2,3- HEADS ØF SUBPIC DIRECTØRIES

[ RØUTINE CAUSES MANIPULATØRS TØ ØPERATE ØN ENTIRE SUBPIC NØT JUST ØNE IMAGE
[ IMCLØ PØRTIØN HANDLES NECESSARY ACTIØN ØN SUBPICS FØR NAME,DASH,ZØØM AND TRAN

IMCLØ:          MDAR            ØNE
                ARMD            IMCFG
                MDAR            TBCNT
                MDAE'N          SEVEN
                JPAN            .+4
                MDAR            TBCNT
                MDXØ            TEN
                JPLS            IM1
                MDAR            ØNE
                ARMD            ICFG1
                MDAR'F          SUBP1
                ARMD            IMC
                JUMP            IM10
IM1:            MDAR            TBCNT
                MDAE'N          SEVTEEN
                JPAN            .+4
                MDAR            TBCNT
                MDXØ            TWEN
                JPLS            IM2
                MDAR            ØNE
                ARMD            ICFG2
                MDAR'F          SUBP2
[ IMAGE CLØSED RØUTINE CØNT.

                ARMD            IMC
                JUMP            IM10
IM2:            MDAR'F          SUBP3
                ARMD            IMC
                MDAR            ØNE
                ARMD            ICFG3

IM10:           MDAR            IMC
                ARMD            WBADR
                MDAR            NAMEFG
                JPLS            .+2
                JUMP            IM11
                JUMP            N6
IM11:           MDAR            DASHFG
                JPLS            .+2
                JUMP            IM12
                JUMP            D1
IM12:           MDAR            ZØØMFG
                JPLS            .+2
                JUMP            IM13
                JUMP            Z2
IM13:           MDAR            TRANFG
                JPLS            .+2
                JUMP            IM14
                JUMP            TRAN3
IM14:           MDAR'I          IMC
                ARMD            NUMB1
                JPSR            SUB2
                MDAR            NUMB1
                ARMD'I          IMC
                JUMP            R3

[ IMCL1 PØRTIØN HANDLES THE ACTIØNS REQUIRED FØR ØPERATING
[ ØN THE WHØLE SUBPIC FØR CRVEC

IMCL1:          MDAR            ICFG1
                JPLS            .+2
                JUMP            IMC1
                MDAR            BCNT
                MDAE'N          SEVEN
                JPAN            .+2
                JUMP            IMC1
                MDAR'F          SUBP1
                ARMD            IMC
                JUMP            IMC10
IMC1:           MDAR            ICFG2
                JPLS            .+2
                JUMP            IMC2
                MDAR            BCNT
                MDAE'N          SEVEN
                JPAN            V2
```

```
        [ IMAGE CLØSED RØUTINE CØNT.

                          MDAR            BCNT
                          MDAE'N          SEVTEEN
                          JPAN            .+2
                          JUMP            IMC2
                          MDAR'F          SUBP2
                          ARMD            IMC
                          JUMP            IMC10
        IMC2:             MDAR            ICFG3
                          JPLS            .+2
                          JUMP            V2
                          MDAR            BCNT
                          MDAE'N          SEVTEEN
                          JPAN            V2
                          MDAR'F          SUBP3
                          ARMD            IMC
        IMC10:            MDAR'I'X        TEMP4
                          ARRS            17
                          NØØP
                          ARMD            TEMP6
                          MDAE'I'X        IMC
                          ARRS            17
                          NØØP
                          ARMD            TEMP1
                          MDAR            TEMP6
                          MDAE            TEMP1
                          ARMD            TEMP1
                          JPAN            .+10
                          MDAE'N          MXSCL
                          JPAN            .+6
                          MDAR            MXSC1
                          ARMD            TEMP1
                          JUMP            .+3
                          ARXØ'F
                          ARMD            TEMP1
                          MDAR            TEMP1
                          ARLS            17
                          NØØP
                          ARMD            TEMP1
                          MD11            TEMP1
                          MD06'I'X        TEMP4
                          MDAR'X          IMC
                          MDAR'I'X        IMC
                          ARAR'N
                          ARMD            NUMB1
                          MDAR'I'X        TEMP4
                          ARMD            NUMB2
                          JPSR            SUB2
                          MD07            NUMB1
                          MDAR'I'X        IMC
                          ARMD            TEMP1
                          MD10'Ø          TEMP1
        [ IMAGE CLØSED RØUTINE CØNT.

                          JUMP            V3

        [ LIGHT PEN HANDLER FØR TEXT

        [ TXCNT-CØUNTER FØR WHICH TEXT LINE WAS BEING DRAWN WHEN LIGHT PEN HIT
        [ CØUNT
        [ CØUNT-CØUNTER FØR NUMBER ØF PØINTS IN DESPT
        [ TRCRD-TRACK CØØRDINATES ØF CURSØR
        [ CURFG-FLAG SET TØ DRAW CURSØR
        [ DATA1-HEADER FØR DISPLAY LIST

        [ RØUTINE HANDLES LIGHT PEN HITS ØN THE TEXT LINES ØF THE MENU,CØUNTER -
        [ IS INCREMENTED IN END ØF TEXT HANDLER. CØUNT DETERMINES WHICH FUNCTIØN -
        [ PICKED AND THEN APPRØPRIATE FLAGS SET.

        LPLER:            0
                          ARMD            LPSAV
                          MD10'A          MASK2
                          MDAR            TXCNT1
                          ARMD            TXCNT
                          ARXØ'F
                          ARMD            LPFLG
                          MDAR            TXCNT
                          MDXØ            ØNE
                          JPLS            J1
                          MDAR            ØNE
                          ARMD            LINEFG
                          ARMD            CURFG
                          ARXØ'F
                          ARMD            CØUNT
                          JUMP            JP
```

```
[ TEXT LIGHT PEN HANDLER CØNT.

J1:             MDAR            TXCNT
                MDXØ            TWØ
                JPLS            J2
                JPSR            LINE1
                MDAR            ØNE
                ARMD            ERASEFG
                JUMP            JP

J2:             MDAR            TXCNT
                MDXØ            THREE
                JPLS            J3
                JPSR            LINE1
                MDAR            ØNE
                ARMD            CURFG
                ARMD            REFG
                MDAR            REFPT
                ARMD            TRCRD
                JUMP            JP

J3:             MDAR            TXCNT
                MDXØ            FØUR
                JPLS            J4
                JPSR            LINE1
                MDAR            ØNE
                ARMD            TRANFG
                ARMD            CURFG
                MDAR            REFPT
                ARMD            TRCRD
                JUMP            JP

J4:             MDAR            TXCNT
                MDXØ            FIVE
                JPLS            J5
                JPSR            LINE1
                MDAR            ØNE
                ARMD            DASHFG
                JUMP            JP

J5:             MDAR            TXCNT
                MDXØ            SIX
                JPLS            J6
                JPSR            LINE1
                MDAR            ØNE
                ARMD            ZØØMFG
                JUMP            JP

[TEXT LIGHT PEN HANDLER CØNT.

J6:             MDAR            TXCNT
                MDXØ            SEVEN
                JPLS            J7
                JPSR            LINE1
                MDAR'X          FRAMEFG
                ARXØ'F
                ARMD            CØUNT
                JUMP            JP

J7:             MDAR            TXCNT
                MDXØ            TEN
                JPLS            J10
                JPSR            LINE1
                MDAR            ØNE
                ARMD            NAMEFG
                ARXØ'F
                ARMD            CØUNT
                JUMP            JP

J10:            MDAR            TXCNT
                MDXØ            ELEVEN
                JPLS            JP
                MDAR            ØNE
                ARMD            TTYFG
                ARXØ'F
                ARMD            CURFG
JP:             MDAR            LPSAV
                JUMP'I          LPLER



[ END ØF LIST HANDLER

[ RØUTINE SETS END ØF LIST FLAG TØ A -0 SØ THAT DRVEC WILL STØP -
[ LØØPING AND DRAW THE NEXT IMAGE

EØLER:          0
                ARMD            SAR1
                ARMD'Ø          EØLFG
                MDAR            SAR1
                JUMP'I          EØLER
```

```
[ FRAME CLØCK HANDLER

[ RØUTINE HANDLES FRAME CLØCK INTERRUPTS,IF IMAGE DØNE FLAG (IDFLG) .
[ IS SET JUMP TØ DTEXT AND REFRESH,IF NØT JUMP RIGHT BACK TØ THE .
[ FRAMECLØCK ØCCURRED

FCLER:          0
                ARMD            SAR3
                MDAR            IDFLG
                JPLS            .+3
                MDAR            SAR3
                JUMP'I          FCLER
                MDAR            LPFLG
                JPLS            .+2
                MDAR'X          LPCNT
                MDAR            FCLER
                MDAR'A          MASK5
                MDAR'Ø          MASK8
                ARMD            DTEXT
                MDAR'F          DTEXT+1
                ARMD            FCLER
                MDAR            SAR3
                ARMD            SAVEAR
                JUMP'I          FCLER

[ END ØF TEXT STRING HANDLER

[ TXCNT.CØUNTER WHICH IS INCREMENTED AFTER EVERY STRING

[RØUTINE JUSTS INCREMENTS A TEXT HANDLER SØ WHEN A LIGHT PEN PICK .
[ ØCCURS LPLER CAN DETERMINE WHICH FUNCTIØN WAS SELECTED.SENDS LCG .
[ TØ NEXT STRING UNLESS FINISHED WHICH IN THAT CASE SENDS CØNTRØL TØ .
[ DRVEC TØ DRAW VECTØRS.

TXLER:          0
                ARMD            SAR2
                MDAR'X          TXCNT1
                MDXØ            TWELVE
                JPLS            JMP6
                MD10'A          MASK2
                MDAR            ØNE
                ARMD            TXCNT1
                MDAR            TXLER
                MDAR'A          MASK5
                MDAR'Ø          MASK8
                ARMD            DRVEC
                MDAR'F          DRVEC+1
                ARMD            TXLER
                MDAR            SAR2
                ARMD            SAVAR
                JUMP'I          TXLER

[ TEXT HANDLER CØNT.

JMP6:           MDAR            INCTXT
                MDAE            FØUR
                ARMD            INCTXT
                ARMD            77735
                MDIC'A          CM14
                MDIC'Ø          TEN
                MDAR            SAR2
                JUMP'I          TXLER


[ RESET LINE FLAGS RØUTINE

[ RØUTINE TØ TURN ØFF CURSØR AND LINE FUNCTIØN FLAGS

LINE1:          JUMP            .
                ARXØ'F
                ARMD            LINEFG
                ARMD            CURFG
                MDIR            LINE1
```

```
[PEN TRACKING SUBROUTINE

[ PTRCP-OFFSET TABLE POINTR
[ TRCRD-CELL WHICH HOLDS CURRENT COORDS. OF CENTER OF CURSOR (TRACK COORD.)
[ TRCRP-CELL WHICH SAVES INITIAL TRCRD TO UP DATE

[ ROUTINE DRAWS A CURSOR WHICH HAS A POINT IN CENTER ENCLOSED BY A RECTANGLE -
[ WHICH IS ENCLOSED BY A DECAGON.WHEN USER HITS A SIDE OF THE RECTANGLE OR -
[ DECAGON,THE CENTER OF THE BURSOR IS MOVED THE DISTANCE AND DIRECTION OF THE -
[ OFFSET.

PTRAC:          JUMP            .
                MDAR'F          NULZ
                ARMD            EOLPV
                MDAR'L
                ARXO'F
                ARMD            LPN2
                ARXO'F
                ARMD            AROPV
                MDAR'F          LPN2
                ARMD            LPNPV
                MD11'L
                37777JH                         [SET SCALE TO MAXIMUM
                MD10'O'L
                61420JH                         [TURN ON
                MD06'F          0
                MDAR'F     .    PTPT-1
                ARMD            PTRCP
                MDAR            TRCRD
                ARMD            TRCRP           [ SAVE FOR UP DATE
                MDAR'A          CM1
                MDAR'O'H        ONE
                JPSR            LOD5
                0;0;0;0;0;
                JPSR            LOD5
                MDAR            TRCRD
                MDAR'O          C1H1
                NOOP
                NOOP
                JPSR            LOD5
                MDAR            TRCRD
                MDAE'L
                400JH           400
                MDAR'A          CM1
                MDAR'O'H        ONE
                NOOP
                NOOP
                JPSR            LOD5
IREPEAT 0,(7740000401,7740077401,40077401,40000401)
                MDAR            TRCRD
                MDAE'L
                0
                MDAR'O          C1H1
[ PEN TRACK. CONT.

                NOOP
                NOOP
                NOOP
                ARAR'X          PTRCP
                JPSR            LOD5
ENDI
                NOOP
                NOOP
                NOOP
                NOOP
                MDAR            LPN2
                JPLS            PTCK9
                MDAR'F          LPN22
                ARMD            LPNPV
                MDAR            TRCRD
                MDAE'L
                1750JH          500
                MDAR'A          CM1
                MDAR'O'H        ONE
                JPSR            LOD5
NOCARRET
IREPEAT 0,(115201523,2033,7662401523,7603000501,
          7603077301,7662476255,75745,115276255,
          175077301,175000501);
CARRET
                NOOP
                NOOP
                NOOP
                NOOP
                MDAR            TRCRD
                MDAE'L
                0
                MDAR'O          C1H1
                ARAR'X          PTRCP
                JPSR            LOD5
ENDI
                NOOP
                NOOP
                NOOP
                NOOP
PTCK9:          MDAR            TRCRP
                ARMD            TRCRD
                MDAR'F          NULX
                ARMD            LPNPV
                MD10'A'L
                1000JH
                MDIR            PTRAC
                                0
```

```
[ PEN TRACK CØNT.

PTPT:           SI;MSIJH;MSI;SIJH

                145101010;57601777;7671201777;7632701012
                7603077700;7632776776;7671276000;57676000
                145076770;175077700
                NØØP;NØØP;

[ LIGHT PEN HANDLERS IN PEN TRACK

[ LIGHT PEN HANDLER FØR HIT ØN THE RECTANGLE

LPN2:           0
                ARMD            LPN2A
                MDAR            TRCRP
                MDAE'I          PTRCP
                ARMD            TRCRP
                MDAR            LPN2A
                JUMP'I          LPN2

[ LIGHT PEN HANDLER FØR A HIT ØN THE DECAGØN

LPN22:          0
                ARMD            LPN2A
                MDAR            TRCRP
                MDAE'I          PTRCP
                ARMD            TRCRP
                MDAR'F          NULX
                ARMD            LPNPV
                MDAR            LPN2A
                JUMP'I          LPN22

[ RØUTINE TØ DRAW THE LINES IN THE CURSØR

LØDS:           JUMP            .
                ARMD'L;         0
                MDOS            .-1
                MDIR            LØDS
NULZ:           JUMP            .
                JUMP'I          NULZ
NULX:           JUMP            .
                JUMP'I          NULX
[ DESIGNATE PØINT RØUTINE

[ RØUTINE HANDLES LØADING IMAGE DIRECTØRY AND WØRDS (DESIGNATED BY FUNC. SWITCH1-
[ INTØ THE DISPLAY LIST.IF NØT FIRST WØRD IN NEW IMAGE, THE EØL BIT IS RESET IN -
[ IN THE LAST WØRD ØF THE DISPLAY LIST AND THE NEW WØRD ADDED WITH EØL BIT SET.
[ FIRST END PØINT IS A MØVE (CØUNT=0),SUCCEEDING END PØINTS         ARE DRAWS (CØUNT -
[ GREATER THAN 0).TELETYPE INPUTS ARE SENT BY TTY TØ BE ADDED TØ THE DISPLAY LIST-
[ AND THE IMAGE DIRECTØRY IS LØADED.

DESPT:          0
                MDAR            FLG1
                JPLS            DTEXT1
                MDAR            ØNE
                ARMD            FLG1
                MDAR            LINEFG
                JPLS            JU
                MDAR            TRANFG
                JPLS            JPTR
                MDAR            REFG
                JPLS            JPREF
                JUMP            DTEXT1
JU:             MDAR            CØUNT               [ THIS PØRTIØN FØR LINE
                ARMD            TEMP1
                MDAR            DATA1
                MDXØ            MZERØ
                JPLS            P1
                MDAR'F          DATA1-1
                ARMD            TEMP2
                MDAR            DBLK
                ARMD            TEMP3
                JUMP            P2
P1:             ARXØ'F
                ARMD            ICFG
                JPSR            WBLØP
                MDAR            WBADR
                ARMD            TEMP3
                MDAR'I          TEMP3
                MDXØ            ØNE
                JPLS            .+2
                JUMP            .+3
                MDAR            ØNE
                ARMD            JMPFG
```

```
        [ DESIGNATE PØINT CØNT.

                        MDAR'F          DATA1
                        MDAE            TWCNT
                        MDAE            WCØNT
                        MDAE'N          ØNE
                        ARMD            TEMP2
                        MDAR            JMPFG
                        JPLS            P2
                        MDAR'I          TEMP2
                        MDAR'A          MASK7
                        ARMD'I          TEMP2

        P2:             MDAR'X          TEMP3
                        MDAR            SCAL
                        ARMD'I          TEMP3
                        MDAR'X          TEMP3
                        MDAR            INTENS
                        ARMD'I          TEMP3
                        MDAR'X          TEMP3
                        MDAR            REFPT
                        ARMD'I          TEMP3
                        ARXØ'F
                        ARMD            JMPFG
                        MDAR            TEMP1
                        JPLS            JU1
                        MDAR            TEMP2
                        MDAE            ØNE
                        ARMD            TEMP2
                        MDAR            TEMP3
                        ARMD            TEMP6
                        MDAR            LFG1
                        JPLS            *+3
                        MDAR            TRCRD
                        JUMP            P3
                        MDAR            PTCØRD1
        P3:             MDAR'A          MASK6
                        ARMD            NUMB2
                        MDAR            REFPT
                        ARMD            NUMB1
                        JPSR            SUB2
                        MDAR            NUMB1
                        MDAR'Ø          MASK9
                        ARMD'I          TEMP2
                        MDAR            TEMP6
                        MDAE'N          THREE
                        ARMD            TEMP6
                        MDAR'I          TEMP6
                        MDXØ            MZERØ
                        JPLS            *+3
                        MDAR            ØNE
                        ARMD'I          TEMP6
        [ DESIGNATE PØINT CØNT.

                        MDAR'X          CØUNT
                        MDAR'X          WCØNT
                        MDAR            LFG1
                        JPLS            JU
                        JUMP            DTEXT1

        JU1:            MDAR            TEMP2           [THIS PØRTIØN FØR SUCCEEDING END PØINTS
                        MDAE            ØNE
                        ARMD            TEMP2
                        MDAR            LFG1
                        JPLS            *+3
                        MDAR            TRCRD
                        JUMP            P4
                        MDAR            PTCØRD2
        P4:             MDAR'A          MASK6
                        ARMD            NUMB2
                        MDAR            REFPT
                        ARMD            NUMB1
                        JPSR            SUB2
                        MDAR            NUMB1
                        MDAR'Ø          C1H1
                        ARMD'I          TEMP2
                        MDAR'X          WCØNT
                        MDAR            LFG1
                        JPLS            T3
                        JUMP            DTEXT1
        JPTR:           MDAR            TRCRD           [ THIS PØRTIØN FØR TRAN
                        MDAR'A          MASK6
                        ARMD            NUMB2
                        ARXØ'F
                        ARMD            TRANFG1
                        ARMD            CURFG
                        ARMD            TRCRD
                        JUMP            DTEXT1
        JPREF:          MDAR            TRCRD           [ THIS PØRTIØN FØR REF
                        MDAR'A          MASK6
                        ARMD            NUMB2
                        ARXØ'F
                        ARMD            REFG1
                        ARMD            CURFG
                        ARMD            TRCRD
                        JUMP            DTEXT1
```

```
        [ WHAT BLØCK ØPEN RØUTINE

        [ WBADR-ADDRESS ØF HEADER ØF THE ØPEN IMAGE
        [TBCNT-CØUNT ØF IMAGES IN CURRENT SUBPIC PLUS 0,10,ØR 20 DEPENDING IF SUBPIC1 -
        [ ØR SUBPIC2 ØR SUBPIC3 ØPEN
        [ DBLK-ADDRESS ØF HEAD ØF DIRECTØRY

        [ RØUTINE DETERMINES WHAT IMAGE (BLØCK) IS ØPEN BY CØMPUTING AN ØFFSET FRØM
        [ THE HEAD ØF THE DIRECTØRY.

        WBLØP:          JUMP            .
        W1:             MDAR            TBCNT
                        ARLS            2
                        NØØP
                        MDAE            TBCNT
                        MDAE            TBCNT
                        MDAE'N          SIX
                        ARMD            TEMP3
                        MDAR            DBLK
                        MDAE            TEMP3
                        ARMD            WBADR
                        MDAR'I          WBADR
                        MDXØ            ØNE
                        JPLS            .+2
                        MDIR            WBLØP
                        MDAR            ØNE
                        ARMD            ICFG
                        MDAR            WBADR
                        MDAE            SIX
                        ARMD            WBADR
                        MDIR            WBLØP

        [CØNSTANTS AND VARIABLES

        TI = 300
        MTI = -TI 77777
        SI = 40
        MSI = -SI 77777
        SAR1:0
        SAR2:0
        SAR3:0
        SAVAR:0
        SAVEAR:0
        [ CØNSTANTS ETC. CØNT.

        MZERØ:-0
        ZERØ:0
        ØNE:1
        TWØ:2
        THREE:3
        FØUR:4
        FIVE:5
        SIX:6
        SEVEN:7
        TEN:10
        ELEVEN:11
        TWELVE:12
        FIFT:15
        SEVTEEN:17
        TWEN:20
        THIR:30
        TEMP1:0
        TEMP2:0
        TEMP3:0
        TEMP4:0
        TEMP5:0
        TEMP6:0
        C1H1:0000100001
        CM1:-1
        CM14:-14
        INCTXT:0
        TXCNT:0
        TXCNT1:1
        TWCNT:0
        WCØNT:0
        BCNT:0
        CNTER:0
        CØNT:10
        CØNT1:0
        CØUNT:0
        PTCNT:0
        TBCNT:0
        TTYCNT:0
        WBADR:0
        ZCNTER:0
        CURFG:0
        DASHFG:0
        DBLK:0
        EØLFG:0
        ERASEFG:0
        ERRFG:0
```

```
[ C0NSTANTS ETC. C0NT.

FRAMEFG:0
FLG1:0
FFG1:0
FFG2:0
FFLAG:0
FRFG1:0
FRFG2:0
ICFG:0
ICFG1:0
ICFG2:0
ICFG3:0
ICFLG:0
IMC:0
IMCFG:0
JMPFG:0
LFG1:0
LINEFG:0
MOVFG:0
NAMEFG:0
LPCNT:0
LPFLG:1
LPSAV:0
LPN2A:0
PTRCP:0
NEGFG:0
RFFG:0
REFG1:1
TRANFG:0
TRANFG1:1
TTYFG:0
TYPEFG:0
Z00MFG:0
TRCRD:0
TRCRP:0
SCAL:           37777J
MXSCL:          37777J
MXSC1:          37777
INTFNS:         20000
EXPY:0
NAMER:0
FAC1:0
REFPT:0
NUMB1:0
NUMB2:0
LP2:0
PTCARD1:0
PTCARD2:0
MASK1:          7777777776
MASK2:          7775777777
MASK3:          0000077776
MASK4:          7777700000
MASK5:          0000077777
MASK6:          7777677776
MASK7:          7777677777
MASK8:          0004000000
MASK9:          0000100000
MASK10:         7777777776
MASK11:         0000077757
MASK12:         0377777777
MASK13:         20
MASK14:         7577777777
DASHMASK:020000VH
LPMASK:200
CLKPV = 77755; LPNPV =77760
FSVPV = 77756; ERLPV = 77757
ARGPV = 77771
```

```
[ TEXT DISPLAY LIST

ORTEXT:         0
                0470005464
                4622247212
                0000100000
                0
                0002260026
                1721251202
                5161300000
                0
                0470005504
                5121243000
                0000100000
                0
                0470005514
                5224440634
                0000100000
                0
                0470005524
                4220251620
                0000100000
                0
                0470005534
                5523647632
                2665152000
                0
                0470005544
                4324440632
                4240100000
                0
                0470005554
                4720246612
                2665152000
                0
                0470005564
                5225054400
                0000100000

[ INSTRUCTIØN DEFINITIØNS

MD05•25000√H
MD06•26000√H
MD07•27000√H
MD10•30000√H
MD11•31000√H
[ DIRECTØRY FØR IMAGES

DBLK1:          •0
                0
                0
                0
                0
                0
DBLK2:          •0
                0
                0
                0
                0
                0
DBLK3:          •0
                0
                0
                0
                0
                0
DBLK4:          •0
                0
                0
                0
                0
                0
DBLK5:          •0
                0
                0
                0
                0
                0
DBLK6:          •0
                0
                0
                0
                0
                0
DBLK7:          •0
                0
                0
                0
                0
                0
DBLK10:         •0
                0
                0
                0
                0
                0
```

```
        [ DIRECTØRY FØR IMAGES IN SUBPIC2

        DBLK21:         .0
                        0
                        0
                        0
                        0
                        0
        DBLK22:         .0
                        0
                        0
                        0
                        0
                        0
        DBLK23:         .0
                        0
                        0
                        0
                        0
                        0
        DBLK24:         .0
                        0
                        0
                        0
                        0
                        0
        DBLK25:         .0
                        0
                        0
                        0
                        0
                        0
        DBLK26:         .0
                        0
                        0
                        0
                        0
                        0
        DBLK27:         .0
                        0
                        0
                        0
                        0
                        0
        DBLK210:        .0
                        0
                        0
                        0
                        0
                        0
        [ DIRECTØRY FØR IMAGES IN SUBPIC3

        DBLK31:         .0
                        0
                        0
                        0
                        0
                        0
        DBLK32:         .0
                        0
                        0
                        0
                        0
                        0
        DBLK33:         .0
                        0
                        0
                        0
                        0
                        0
        DBLK34:         .0
                        0
                        0
                        0
                        0
                        0
        DBLK35:         .0
                        0
                        0
                        0
                        0
                        0
        DBLK36:         .0
                        0
                        0
                        0
                        0
                        0
        DBLK37:         .0
                        0
                        0
                        0
                        0
                        0
        DBLK310:        .0
                        0
                        0
                        0
                        0
                        0
```

```
55.1          [ DIRECTØRY FØR SUBPIC1
55.2
55.3          SUBP1:          0
55.4                          0
55.5                          0
55.6                          0
55.7                          0
55.10         MCNT1:          0
55.11         TBCN1:          0
55.12
55.13         [ DIRECTØRY FØR SUBPIC2
55.14
55.15         SUBP2:          0
55.16                         0
55.17                         0
55.20                         0
55.21                         0
55.22         MCNT2:          0
55.23         TBCN2:          0
55.24
55.25         [ DIRECTØRY FØR SUBPIC3
55.26
55.27         SUBP3:          0
55.30                         0
55.31                         0
55.32                         0
55.33                         0
55.34         MCNT3:          0
55.35         TBCN3:          0
55.36
55.37         DATA1:-0
55.40         TERMINATE
```

```
AGAIN1      25.21          E3          17.37          IM2         30.5           MXSCL       47.46
AGAIN2      13.30          E4          17.53          IMCL1       30.46          MZERØ       46.3
AGAIN3      17.43          ELEVEN      46.15          IMCLØ       27.40          N1          10.47
AGAIN       10.25          ELPLER      16.40          IMC         47.17          N2          11.3
BCNT        46.41          END         22.10          IMC10       31.22          N3          11.17
C1M1        46.31          END1        23.40          IMC1        30.60          N4          11.32
CHECK       22.20          END2        6.53           IMC2        31.12          N5          11.42
CM1         46.32          END3        17.57          IMCFG       47.20          N6          11.51
CM14        46.33          EØLER       34.47          INCTXT      46.34          NAME1       10.14
CNTER       46.42          EØLFG       46.56          INTENS      47.50          NAMEFG      47.25
CØMP1       14.56          ERASE1      16.6           J10         34.26          NAMER       47.52
CØMP        14.43          ERASEFG     46.57          J1          33.3           NEGFG       47.33
CØNT1       46.44          ERRØR       26.47          J2          33.13          NULX        41.55
CØNT        46.43          ERR1        12.3           J3          33.26          NULZ        41.53
CØUNT       46.45          ERR2        15.40          J4          33.41          NUMB1       47.55
CURFG       46.53          ERR3        15.53          J5          33.51          NUMB2       47.56
D1          27.13          ERR4        15.61          J6          34.3           ØNE         46.5
DASH1       27.7           ERRFG       46.60          J7          34.14          ØVER1       11.46
DASHFG      46.54          F1          5.35           JMP6        36.3           ØVER        5.51
DASHMASK    50.17          F2          6.16           JMPFG       47.21          P1          42.41
DATA1       55.37          FAC1        47.53          JPREF       44.45          P2          43.16
DBLK10      52.55          FCLER       35.7           JP          34.35          P3          43.45
DBLK1       52.3           FFG1        47.5           JPTR        44.35          P4          44.21
DBLK210     53.55          FFG2        47.6           JU1         44.11          PTCK9       40.53
DBLK21      53.3           FFLAG       47.7           JU          42.27          PTCNT       46.46
DBLK22      53.11          FIFT        46.17          LFG1        47.22          PTCØRD1     47.60
DBLK23      53.17          FINI1       15.3           LINE1       36.21          PTCØRD2     47.61
DBLK24      53.25          FINI2       16.23          LINEFG      47.23          PTPT        41.3
DBLK25      53.33          FINI3       27.22          LØD5        41.46          PTRAC       37.14
DBLK26      53.41          FINIS       12.7           LP2         47.57          PTRCP       47.32
DBLK27      53.47          FIVE        46.11          LPCNT       47.26          R0          21.12
DBLK2       52.11          FLG1        47.4           LPFLG       47.27          R1          21.15
DBLK310     54.55          FØUR        46.10          LPLER       32.22          R2          21.50
DBLK31      54.3           FR1         6.3            LPMASK      50.20          R3          22.3
DBLK32      54.11          FR2         6.35           LPN22       41.31          RCØMP1      20.22
DBLK33      54.17          FR5         7.24           LPN2A       47.31          RCØMP       15.16
DBLK34      54.25          FR6         7.35           LPN2        41.16          RCØM        15.13
DBLK35      54.33          FRAM1       5.17           LPSAV       47.30          REFPT       47.54
DBLK36      54.41          FRAM3       7.7            MASK10      50.12          REF1        20.17
DBLK37      54.47          FRAMEFG     47.3           MASK11      50.13          REFG1       47.35
DBLK3       52.17          FRFG1       47.10          MASK12      50.14          REFG        47.34
DBLK4       52.25          FRFG2       47.11          MASK13      50.15          SAR1        45.47
DBLK5       52.33          GPGSY       1.17           MASK14      50.16          SAR2        45.50
DBLK6       52.41          ICFG1       47.13          MASK1       50.1           SAR3        45.51
DBLK7       52.47          ICFG2       47.14          MASK2       50.2           SAVAR       45.52
DBLK        46.55          ICFG3       47.15          MASK3       50.3           SAVEAR      45.53
DESPT       42.13          ICFG        47.12          MASK4       50.4           SCAL        47.45
DPTEXT      51.3           ICFLG       47.16          MASK5       50.5           SEVTEEN     46.20
DRVEC       3.20           IM1         27.55          MASK6       50.6           SEVEN       46.13
DTEXT1      2.13           IM10        30.12          MASK7       50.7           SIX         46.12
DTEXT       1.53           IM11        30.20          MASK8       50.10          SKIP1       2.32
DXDY        47.51          IM12        30.24          MASK9       50.11          SKIP22      14.3
E1          16.46          IM13        30.30          MØVFG       47.24          SKIP23      14.27
```

```
SKIP          2.30                      Z2           26.12
SUBP1         55.3                      Z3           26.31
SUBP2         55.15                     Z4           26.37
SUBP3         55.27                     Z5           26.41
SUB2          24.11                     ZCNTER       46.52
T1            14.25                     ZERØ         46.4
T2            14.41                     ZØØM1        25.14
T3            14.46                     ZØØM2        26.3
TBCN1         55.11                     ZØØMFG       47.42
TBCN2         55.23
TBCN3         55.35
TBCNT         46.47
TCØMP         15.31
TEMP1         46.23
TEMP2         46.24
TEMP3         46.25
TEMP4         46.26
TEMP5         46.27
TEMP6         46.30
TEN           46.14
THIR          46.22
THREE         46.7
TRAN1         23.14
TRAN2         23.17
TRAN3         23.27
TRANFG1       47.37
TRANFG        47.36
TRATY         15.25
TRCRD         47.43
TRCRP         47.44
TT            4.3
TTY1          13.17
TTYCNT        46.50
TTYFG         47.40
TWCNT         46.37
TWELVE        46.16
TWEN          46.21
TWØ           46.6
TXCNT1        46.36
TXCNT         46.35
TXLER         35.43
TYPEFG        47.41
V1            4.34
V2            4.36
V3            4.43
W1            45.14
WAIT1         26.61
WBADR         46.51
WBLØP         45.13
WCNT1         55.10
WCNT2         55.22
WCNT3         55.34
WCØNT         46.40
```

LIST OF REFERENCES

1. Siders, R. A., and others, Computer Graphics, A Revolution in Design, American Management Association, 1966.

2. Brown, S. A., and others, "A Description of the APT Language," Communications of the ACM, v. 6, pp. 649-658, November, 1963.

3. Hurwitz, A., and others, "GRAF: Graphic Additions to FORTRAN," in AFIPS Conference Proceedings 1967 Spring Joint Computer Conference, v. 30. Thompson Book Company, 1967.

4. Thornhill, D. E., and others, An Integrated Hardware-Software System for Computer Graphics in Time-Sharing, Massachusetts Institute of Technology, November, 1968.

5. Anderson, R. H., and Farber, D. J., Extensions to the PL/I Language for Interactive Computer Graphics, The Rand Corporation, RM-6028-ARPA, January, 1970.

6. Rully, A. D., "A Subroutine Package for FORTRAN," Interactive Graphics in Data Processing, IBM Systems Journal, v. 7, pp. 248-256, 1968.

7. Gagliano, F. W., and others, "A Conversational Display Capability," Interactive Graphics in Data Processing, IBM Systems Journal, v. 7, pp. 281-291, 1968.

8. Brown, G. D., and Bush, C. H., The Integrated Graphics System for the IBM 2250, The Rand Corporation, 1968.

9. Streit, E., "VIP: A Conversational System for Computer-Aided Graphics," in Pertinent Concepts in Computer Graphics, Faiman, M., and Nievergelt, J., ed., University of Illinois Press, 1969.

10. Sutherland, I. E., "Sketchpad A Man-Machine Graphical Communication System," AFIPS Conference proceedings 1963 Spring Joint Computer Conference, v. 23, Spartan Books Incorporated, 1963.

11. Electronic Systems Laboratory, Massachusetts Institute of Technology, ESL-TM-220, Some Experiments with an Algorithmic Graphical Language, by Lang, C. A., and others, August, 1965.

12. Yarbrough, L. D., "CAFE: A nonprocedural Language for Computer Animation" in Pertinent Concepts in Computer Graphics, Faiman, M., and Nievergelt, J., ed., University of Illinois Press, 1969.

13. Ledley, R. S., and others, "BUGSYS: A Programming System for Picture Processing - Not for Debugging," Communications of the ACM, v. 9, pp. 79-84, February, 1966.

14. Miller, W. F., and Shaw, A. C., "A Picture Calculus," in Emerging Concepts in Computer Graphics, Secrest, D., and Nievergelt, J., ed., W. A. Benjamin Incorporated, 1968.

15. Kulsrud, H. E., "A General Purpose Graphic Language," Communications of the ACM, v. 11, pp. 247-254, April, 1968.

16. Morrison, R. A., "Graphic Language Translation with a Language Independent Processor," in AFIPS Conference Proceedings 1967 Fall Joint Computer Conference, v. 31, Thompson Book Company, 1967.

17. Roberts, L. G., "A Graphical Service System with Variable Syntax, Communications of the ACM, v. 9, pp. 173-175, March, 1966.

18. Coons, S. A., "An Outline of the Requirements for a Computer-Aided Design System," in AFIPS Conference Proceedings 1963 Spring Joint Computer Conference, v. 23, Spartan Books Incorporated, 1963.

19. Notely, M. G., "A Graphical Picture Drawing Language," The Computer Bulletin, v. 14, pp. 68-74, March, 1970.

20. Chen, F. C., and Dougherty, R. L., "A System for Implementing Interactive Applications," Interactive Graphics in Data Processing, IBM Systems Journal, v. 7, pp. 257-270, 1968.

21. Herzog, B., "Computer Graphics for Designers," in Emerging Concepts in Computer Graphics, Secrest, D., and Nievergelt, J., ed., W. A. Benjamin Incorporated, 1968.

22. Johnson, T. E., "Sketchpad III A Computer Program for Drawing in Three Dimensions," in AFIPS Conference Proceedings 1963 Spring Joint Computer Conference, v. 23, Spartan Books Incorporated, 1963.

23. Lincoln Laboratory, Massachusetts Institute of Technology, Technical Report Number 315, Machine Perception of Three-Dimensional Solids, by L. G. Roberts, 22 May 1963.

24. International Business Machines Corporation, IBM SYSTEM/360 Operating System Graphic Subroutine Package (GSP) for FORTRAN IV, COBOL, and PL/I, 1969.

25. Sutherland, I. E., "Computer Displays," Scientific American, v. 222, pp. 57-81, June, 1970.

26. Spiegel, M. R., Theory and Problems of Vector Analysis and an Introduction to Tensor Analysis, Schaum Publishing Company, 1959.

INITIAL DISTRIBUTION LIST

		No. Copies
1.	Defense Documentation Center Cameron Station Alexandria, Virginia 22314	2
2.	Library, Code 0212 Naval Postgraduate School Monterey, California 93940	2
3.	LT Ronald D. DeLaura, USNR (Code 52Dl) Department of Electrical Engineering Naval Postgraduate School Monterey, California 93940	1
4.	Dr. George Rahe (Code 52 Ra) Department of Electrical Engineering Naval Postgraduate School Monterey, California 93940	1
5.	MAJOR James Dale Beans, USMC 117 Spa View Avenue Annapolis, Maryland 21401	1

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)* Naval Postgraduate School Monterey, California 93940	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

GPGL: A Model Interactive, General Purpose Graphic Language

4. DESCRIPTIVE NOTES *(Type of report and, inclusive dates)*

Master's Thesis; December 1971

5. AUTHOR(S) *(First name, middle initial, last name)*

James Dale Beans

6. REPORT DATE December 1971	7a. TOTAL NO. OF PAGES 117	7b. NO. OF REFS 26

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO.	
c.	9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*
d.	

10. DISTRIBUTION STATEMENT

This document has been approved for public release;distribution unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Naval Postgraduate School Monterey, California 93940

13. ABSTRACT

General Purpose Graphic Language (GPGL) is an interactive language which is intended for both two-dimensional and three-dimensional displays. The thesis contains a survey of the attributes and capabilities of an interactive general purpose graphic language. The more popular general purpose graphic languages are compared and the results included. The system and user-defined functions (including the construction of user-defined functions) of GPGL are explained. The implementation of a subset of GPGL at the Naval Postgraduate School on an Adage AGT-10 graphics terminal is described. The main purpose of implementing a selected subset of functions from GPGL is to examine the tri-level hierarchy established within the components of the graphical display; the manner in which this hierarchy is implemented is addressed in the thesis.

KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Computer graphics						
Graphics language						
Interactive graphics						
Graphical language						
Interaction						
Graphics						

133316
Thesis
B2885 Beans
c.1 GPGL: a model inter-
active, general pur-
pose graphic language.